

PATENT COOPERATION TREATY

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

Assistant Commissioner for Patents
 United States Patent and Trademark
 Office
 Box PCT
 Washington, D.C.20231
 ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year)

04 September 2000 (04.09.00)

International application No.

PCT/GB00/00168

Applicant's or agent's file reference

NMM/P66650WO

International filing date (day/month/year)

24 January 2000 (24.01.00)

Priority date (day/month/year)

22 January 1999 (22.01.99)

Applicant

LUCAS, James et al

1. The designated Office is hereby notified of its election made:



in the demand filed with the International Preliminary Examining Authority on:

21 August 2000 (21.08.00)



in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was

was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
 34, chemin des Colombettes
 1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

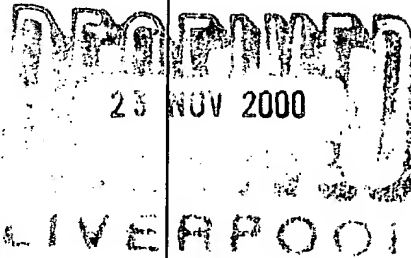
Zakaria EL KHODARY

Telephone No.: (41-22) 338.83.38

From the:
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

W.P. THOMPSON & CO.
Coopers Building
Church Street
Liverpool L1 3AB
GRANDE BRETAGNE



PCT

WRITTEN OPINION

(PCT Rule 66)

Date of mailing
(day/month/year) 20.11.2000

Applicant's or agent's file reference
NMM/P66650WO

REPLY DUE within 3 month(s)
from the above date of mailing

International application No.
PCT/GB00/00168

International filing date (day/month/year)
24/01/2000

Priority date (day/month/year)
22/01/1999

International Patent Classification (IPC) or both national classification and IPC
G01N22/00

Applicant

THE UNIVERSITY OF LIVERPOOL ET AL

RESPONSE DUE: 20. 2. 01.

1. This written opinion is the first drawn up by this International Preliminary Examining Authority.
2. This opinion contains indications relating to the following items:
 - I ☒ Basis of the opinion
 - II ☐ Priority
 - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
 - IV ☐ Lack of unity of invention
 - V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
 - VI ☐ Certain document cited
 - VII ☒ Certain defects in the international application
 - VIII ☐ Certain observations on the international application
3. The applicant is hereby invited to reply to this opinion.

When? See the time limit indicated above. The applicant may, before the expiration of that time limit, request this Authority to grant an extension, see Rule 66.2(d).

How? By submitting a written reply, accompanied, where appropriate, by amendments, according to Rule 66.3. For the form and the language of the amendments, see Rules 66.8 and 66.9.

Also: For an additional opportunity to submit amendments, see Rule 66.4.
For the examiner's obligation to consider amendments and/or arguments, see Rule 66.4 bis.
For an informal communication with the examiner, see Rule 66.6.

If no reply is filed, the International preliminary examination report will be established on the basis of this opinion.
4. The final date by which the International preliminary examination report must be established according to Rule 69.2 is: 22/05/2001.

Name and mailing address of the international preliminary examining authority:



European Patent Office
D-80298 Munich
Tel. +49 89 2399 - 0 Tx: 523656 epmu d
Fax: +49 89 2399 - 4465

Authorized officer / Examiner

Hoogen, R

Formalities officer (incl. extension of time limits)

Conner, M

Telephone No. +49 89 2399 2241



I. Basis of the opinion

1. This opinion has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this opinion as "originally filed".*):

Description, pages:

1-21 as originally filed

Claims, No.:

1-15 as originally filed

Drawings, sheets:

1/12-12/12 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N) Claims 1-3, 6, 7, 9-12, 14, 15

Inventive step (IS) Claims 4, 5, 13

Industrial applicability (IA) Claims

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
se separate sheet

Re Item V

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Reference is made to the following document:

D1: EP-A-0 511 651 (IVAC CORP) 4 November 1992 (1992-11-04)

2. **Apparatus claims 1-13**

- 2a. **Claim 1**

The document D1 is regarded as being the closest prior art to the subject-matter of claim 1. It discloses an apparatus for determining dielectric properties of an electrically conductive fluid (cf. column 2, lines 55-58; column 11, lines 30-38; figure 11, curve 114) comprising

- an electromagnetically resonant cavity defined by an electrically conductive boundary (cf. column 4, lines 46-48);

- an inlet through which the fluid can be introduced into the cavity (cf. column 4, lines 54-56);

- an insulating layer whereby the cavity boundary is electrically isolated from the fluid material within the cavity (polyurethane tubing, cf. column 12, lines 13-15, and air gap between the cavity boundary and the tubing, cf. figure 1);

- an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from fluid material within the cavity (cf. column 5, lines 25-26; column 12, lines 13-15; air gap between antenna and tubing, figure 1);

- means for detecting resultant electromagnetic radiation within the cavity (cf. column 5, lines 26-29).

Since all technical features of claim 1 are already disclosed in D1, the subject-matter of claim 1 is not new in the sense of Article 33(2) PCT.

- 2b. **Claims 2-13**

Claims 2 and 3: From column 11, lines 30-38 and figure 11 it is clear that the device described in D1 operates at a continuous range of frequencies.

Claims 4 and 5: It is an essential feature of the device described in D1 that the electrically conductive walls of the resonant cavity and the transmitter/receiver antennas are electrically isolated from the conductive fluid (cf. passages already cited under Item V.2a). In view of this teaching the features of claims 4 and 5 are considered to be within the normal range of design possibilities envisaged by the skilled person when confronted with the problem of electrically isolating the cavity walls and the antennas from the fluid.

Claim 6: known from D1 (cf. column 4, lines 52-57)

Claim 7: known from D1 (cf. column 5, lines 26-29; figure 1)

Claim 8: The measurement of the voltage standing wave ratio does not appear to be disclosed or suggested by the available prior art.

Claim 9: known from D1 (cf. column 2, lines 46-51)

Claim 10: known from D1 (cf. column 8, lines 51-55)

Claim 11: known from D1 (cf. column 3, lines 7-16)

Claim 12: known from D1 (cf. column 3, lines 29-37)

Claim 13: The use of neural networks in order to estimate a set of parameters from a set of measurements is common practice.

3. Method claims 14 and 15

Method claims 14 and 15 are directed to the use of the device according to claims 1-3 and are not considered to be new in the sense of Article 33(2) PCT for reasons analogous to those already given for claims 1-3.

Re Item VII

Certain defects in the international application

1. In order to comply with the requirements of Rule 5.1(a)(ii) PCT, the document D1 should be identified in the description and the relevant background art disclosed therein should be briefly discussed.

NI 7. If the Applicant is aware of a document reflecting the prior art which is described on page 3, line 9 - page 4, line 6, then the document should be identified in the description.

- correct 2. It appears that the decimal points of the values on the ordinate of Figure 18 should in fact be minus signs, since the phase delay varies between 0° and -360° (page 18, lines 3-4).

PATENT COOPERATION TREATY

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From the
II INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

W.P. THOMPSON & CO.
Coopers Building
Church Street
Liverpool L1 3AB
GRANDE BRETAGNE



PCT

NOTIFICATION OF TRANSMITTAL OF
THE INTERNATIONAL PRELIMINARY
EXAMINATION REPORT
(PCT Rule 71.1)

Date of mailing
(day/month/year) 20.04.2001

Applicant's or agent's file reference
NMM/P66650WO

IMPORTANT NOTIFICATION

International application No.
PCT/GB00/00168

International filing date (day/month/year)
24/01/2000

Priority date (day/month/year)
22/01/1999

Applicant

THE UNIVERSITY OF LIVERPOOL ET AL

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.
2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.
3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. REMINDER

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/



European Patent Office
D-80298 Munich
Tel. +49 89 2399 - 0 Tx: 523656 epmu d
Fax: +49 89 2399 - 4465

Authorized officer

Conner, M

Tel. +49 89 2399-2241



PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference NMM/P66650WO	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/00168	International filing date (day/month/year) 24/01/2000	Priority date (day/month/year) 22/01/1999
International Patent Classification (IPC) or national classification and IPC G01N22/00		
Applicant THE UNIVERSITY OF LIVERPOOL ET AL		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.



2. This REPORT consists of a total of 5 sheets, including this cover sheet.

☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 7 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☒ Certain observations on the international application

Date of submission of the demand 21/08/2000	Date of completion of this report 20.04.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Hoogen, R Telephone No. +49 89 2399 2192 <div style="text-align: right;">  </div>

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00168

I. Basis of the report

1. With regard to the elements of the international application (*Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17)*):

Description, pages:

1-3,6-8,10-21	as originally filed		
4,5,9	as received on	27/03/2001	with letter of 20/03/2001

Claims, No.:

1-15	as received on	27/03/2001	with letter of 20/03/2001
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Drawings, sheets:

1/12-11/12	as originally filed		
12/12	as received on	27/03/2001	with letter of 20/03/2001

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00168

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-15
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-15
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-15
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/GB00/00168

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Apparatus claims 1-13

1a. Independent claim 1

Document

D1: EP-A-0 511 651 (IVAC CORP) 4 November 1992 (1992-11-04)
is regarded as being the closest prior art to the subject-matter of claim 1. Using the terminology of claim 1, it discloses an apparatus for determining dielectric properties of an electrically conductive fluid (cf. column 2, lines 55-58; column 11, lines 30-38; figure 11, curve 114) comprising
an electromagnetically resonant cavity defined by an electrically conductive boundary wall (cf. column 4, lines 46-48);
a fluid line for passing fluid through the cavity (cf. column 4, lines 54-56);
said cavity boundary being electrically isolated from the fluid (fluid line consisting of polyurethane tubing, cf. column 12, lines 13-15, and air gap between the cavity boundary and the tubing, cf. figure 1);
an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from the fluid (cf. column 5, lines 25-26; column 12, lines 13-15; air gap between antenna and tubing, figure 1);
means for detecting resultant electromagnetic radiation within the cavity (cf. column 5, lines 26-29).

The device according to claim 1 differs from this disclosure in that
an electrically insulating layer is disposed on the electrically conductive boundary wall defining the interior wall of the resonant cavity;
an inlet is provided for introducing the fluid into the interior of the cavity.

Thus, in the device according to claim 1 the fluid completely fills the interior of the resonant cavity such that the dielectric loading of the cavity is entirely due to the fluid contained therein, whereas in D1 the fluid is confined to a fluid line passing

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/GB00/00168

through the cavity.

The problem to be solved by the device according to claim 1 may therefore be seen in providing a resonant cavity sensor with increased sensitivity.

The particular solution proposed in claim 1 is neither anticipated nor fairly suggested by the available prior art. The subject-matter of claim 1 therefore meets the requirements of the PCT with respect to novelty and inventive step (Articles 33(2) and (3)).

1b. Dependent claims 2-13

Claims 2-13 are dependent on claim 1 and as such also meet the requirements of the PCT with respect to novelty and inventive step.

2. Method claims 14 and 15

Method claims 14 and 15 are directed to the use of the device according to claim 1 for determining dielectric properties of an electrically conductive fluid and as such are also considered to meet the requirements of the PCT with respect to novelty and inventive step.

Re Item VII

Certain defects in the international application

The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

Re Item VIII

Certain observations on the international application

All features of claim 5 are already contained in claim 1. The claims therefore lack conciseness (Article 6 PCT).

- 4 -

the cavity were largely fixed as a function of the (fixed) frequency used.

Coupling of the microwave radiation into the cavity was achieved by an aerial, necessarily very large, which was itself exposed to the contents of the cavity - ie. to the flow.

The device unfortunately proved unsatisfactory due to factors including the size and expense of the magnetron used and its fixed frequency.

Despite these problems, it is recognised that measurement of the properties of the flow with regard to electromagnetic radiation is desirable since the properties of the three major constituents of the flow with regard to EM radiation are widely divergent, and hence easy to distinguish. This can be appreciated from the fact that the relative permittivity of the three constituents is approximately as follows:

- I. gas, $\epsilon_r = 1$;
- ii. crude oil, $\epsilon_r = 2.2$ (and this proves to be largely constant for all crude oils, despite variations in its component fractions);
- iii. water, $\epsilon_r = 81$.

The inventors have realised, and confirmed by experiment, that contrary to the hitherto conventional teaching, it is possible to efficiently couple radio and microwave radiation into a conductive medium within a resonant cavity provided that the cavity walls and the antenna used to output the radiation are electrically isolated from the medium itself.

There is already known from EP-A-511651 a non-invasive, in-line fluid monitor which includes a length of fluid pipe disposed such that it and the fluid within become a part of the dielectric loading on an energised electromagnetic sensor device. A resonant closed cavity is used to encompass the length of fluid pipe and a process is used to compare changes in the resonant characteristics of the cavity to predetermined data to determine the properties of the fluid. The cavity is in the form of an open, five walled box of an electrically conductive metal, such as copper or brass, having a separable metal lid forming a sixth side to achieve the closed cavity through which the fluid pipe passes. In this arrangement, therefore the fluid flow is confined to the fluid pipe.

- 5 -

In accordance with a first aspect of the present invention, there is an apparatus for determining an apparatus for determining dielectric properties of an electrically conductive liquid, comprising:-

- an electrically resonant cavity defined by an electrically conductive boundary wall;

- an electrically insulating layer disposed on those parts of the electrically conductive boundary wall defining the interior wall of the cavity;

- an inlet through which the fluid can be introduced into the interior of the cavity, said electrically insulating layer isolating the fluid from said electrically conductive boundary wall;

- an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from fluid material within the cavity; and

- means for detecting resultant electromagnetic radiation within the cavity.

Experiments carried out by the inventors have confirmed that using such an arrangement measurements of dielectric properties can be made without the need for the high power provided by a magnetron. The arrangement can serve as a dielectric permittivity sensor. Dielectric properties at a radio and microwave frequencies can be measured. In prototype arrangements, a simple loop aerial driven by an electronic oscillator has proved adequate by virtue of the efficient propagation of radiation through the fluid material made possible by the arrangement. As compared with the previous magnetron apparatus, this makes possible great simplification and cost saving, as well as other benefits which will become clear below.

The fluid in question may contain some solids, as typically does a flow of material in an oil extraction pipeline.

With regard to the frequency of radiation emitted into the cavity, it is considered that the present invention is particularly applicable to radio and microwave frequencies. The frequency range used is in part determined by the

- 9 -

In a preferred embodiment, the calculating means operates by calculating for a set of possible permutations of flow constituents the expected values of the measured properties and comparing these with the actual measured values to determine which permutation best matches the measured properties.

The calculating means may comprise a neural network, trained on experimental data, for determining expected quantities relating to the dielectric properties of the flow corresponding to the permutations of flow constituents. The quantities in question may be the frequencies of a selected resonant mode of the cavity.

In accordance with a third aspect of the present invention, there is a method of determining dielectric properties of an electrically conductive fluid comprising the steps of disposing the fluid material in or passing the fluid through an apparatus in accordance with the first aspect of the invention, emitting electromagnetic radiation into the resonant cavity by means of the antenna which is electrically isolated from the fluid and detecting and analysing the resultant electromagnetic radiation within the resonant cavity.

Preferably, the method comprises varying the frequency of the emitted electromagnetic radiation and obtaining an indication of the amplitude of the resultant electromagnetic radiation within the resonant cavity. The frequency variation may be continuous. The results are preferably analysed to determine the position of at least one resonance peak within the cavity.

- 22 -

CLAIMS

1. An apparatus for determining dielectric properties of an electrically conductive liquid, comprising:-

an electrically resonant cavity defined by an electrically conductive boundary wall;

an electrically insulating layer disposed on those parts of the electrically conductive boundary wall defining the interior wall of the cavity;

an inlet through which the fluid can be introduced into the interior of the cavity, said electrically insulating layer isolating the fluid from said electrically conductive boundary wall;

an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from fluid material within the cavity; and

means for detecting resultant electromagnetic radiation within the cavity.

2. An apparatus as claimed in claim 1 wherein the drive electronics are adapted to operate at a range of frequencies such that a range of frequencies of electromagnetic radiation can be emitted to the cavity.

3. An apparatus as claimed in claim 2, wherein the frequency is continuously variable.

4. An apparatus as claimed in any preceding claim, wherein the antenna for emitting electromagnetic radiation into the fluid material is disposed within the resonant cavity such as to project into the fluid material, the antenna being provided with an insulating layer by which is it electrically isolated from the fluid material

5. An apparatus as claimed in any preceding claim, wherein the boundary of the resonant cavity comprises a conductive wall whose inner surface is covered by said electrically insulating layer by which the wall is electrically isolated from the fluid material within the cavity.

6. An apparatus as claimed in any preceding claim wherein the resonant cavity has an inlet and an outlet such that the fluid material can flow through the

- 23 -

cavity.

7. An apparatus as claimed in any preceding claim wherein the means for detecting electromagnetic radiation within the cavity comprise a receiver antenna disposed within the resonant cavity and electrically isolated from the fluid material within the cavity.

8. An apparatus as claimed in any of claims 1 to 6 wherein the means for detecting electromagnetic energy within the cavity comprise electronics connected to the emitter antenna for measuring the voltage standing wave ratio.

9. A device for monitoring constituents of a fluid flow comprising an apparatus as claimed in any preceding claim.

10. A device as claimed in claim 9, further comprising measurement electronics for determining the frequency of a resonance peak corresponding to a selected resonant mode within the cavity.

11. A device as claimed in claim 9 or claim 10, further comprising means for measuring additional properties of the fluid flow and calculating means for determining, on the basis of the measured properties, the proportions of certain constituents of the flow.

12. A device as claimed in claim 11, wherein the calculating means operates by calculating for a set of possible permutations of flow constituents the expected values of the measured properties and comparing these with the actual measured values to determine which permutation best matches the measured properties.

13. A device as claimed in claim 12, wherein the calculating means comprise a neural network, trained on experimental data, for determining expected quantities relating to the dielectric properties of the flow corresponding to the permutations of flow constituents.

14. A method of determining dielectric properties of an electrically conductive fluid comprising the steps of disposing the fluid material in or passing the fluid through an apparatus in accordance with claim 1, emitting electromagnetic radiation into the resonant cavity by means of the antenna which is electrically

- 24 -

isolated from the fluid and detecting and analysing the resultant electromagnetic radiation within the resonant cavity.

15. A method as claimed in claim 14, comprising varying the frequency of the emitted electromagnetic radiation and obtaining an indication of the amplitude of the resultant electromagnetic radiation within the resonant cavity.

12/12

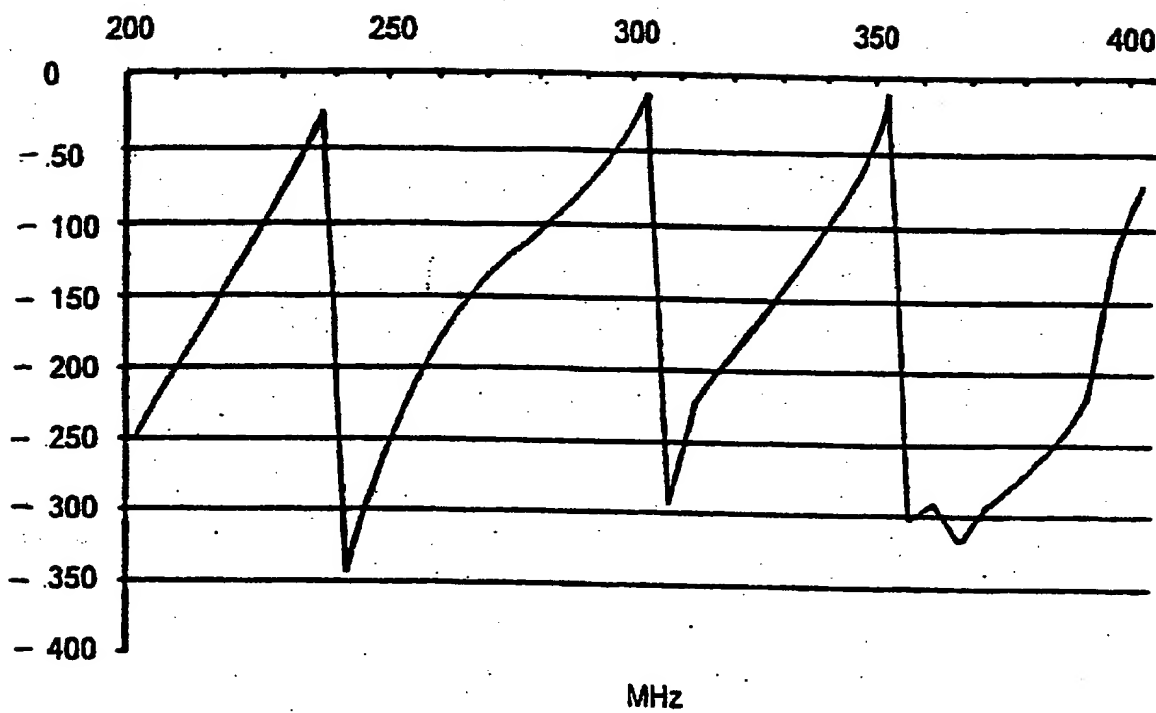


FIG.18.

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

14

Applicant's or agent's file reference NMM/P66650WO	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/00168	International filing date (day/month/year) 24/01/2000	Priority date (day/month/year) 22/01/1999
International Patent Classification (IPC) or national classification and IPC G01N22/00		
Applicant THE UNIVERSITY OF LIVERPOOL ET AL		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.



2. This REPORT consists of a total of 5 sheets, including this cover sheet.

☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 7 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☒ Certain observations on the international application

Date of submission of the demand 21/08/2000	Date of completion of this report 20.04.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Hoogen, R Telephone No. +49 89 2399 2192 

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00168

I. Basis of the report

1. With regard to the **elements** of the international application (*Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17)*):
Description, pages:

1-3,6-8,10-21	as originally filed			
4,5,9	as received on	27/03/2001	with letter of	20/03/2001

Claims, No.:

1-15	as received on	27/03/2001	with letter of	20/03/2001
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Drawings, sheets:

1/12-11/12	as originally filed			
12/12	as received on	27/03/2001	with letter of	20/03/2001

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00168

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-15
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-15
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-15
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Apparatus claims 1-13

1a. Independent claim 1

Document

D1: EP-A-0 511 651 (IVAC CORP) 4 November 1992 (1992-11-04)
is regarded as being the closest prior art to the subject-matter of claim 1. Using the terminology of claim 1, it discloses an apparatus for determining dielectric properties of an electrically conductive fluid (cf. column 2, lines 55-58; column 11, lines 30-38; figure 11, curve 114) comprising
an electromagnetically resonant cavity defined by an electrically conductive boundary wall (cf. column 4, lines 46-48);
a fluid line for passing fluid through the cavity (cf. column 4, lines 54-56);
said cavity boundary being electrically isolated from the fluid (fluid line consisting of polyurethane tubing, cf. column 12, lines 13-15, and air gap between the cavity boundary and the tubing, cf. figure 1);
an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from the fluid (cf. column 5, lines 25-26; column 12, lines 13-15; air gap between antenna and tubing, figure 1);
means for detecting resultant electromagnetic radiation within the cavity (cf. column 5, lines 26-29).

The device according to claim 1 differs from this disclosure in that
an electrically insulating layer is disposed on the electrically conductive boundary wall defining the interior wall of the resonant cavity;
an inlet is provided for introducing the fluid into the interior of the cavity.

Thus, in the device according to claim 1 the fluid completely fills the interior of the resonant cavity such that the dielectric loading of the cavity is entirely due to the fluid contained therein, whereas in D1 the fluid is confined to a fluid line passing

through the cavity.

The problem to be solved by the device according to claim 1 may therefore be seen in providing a resonant cavity sensor with increased sensitivity.

The particular solution proposed in claim 1 is neither anticipated nor fairly suggested by the available prior art. The subject-matter of claim 1 therefore meets the requirements of the PCT with respect to novelty and inventive step (Articles 33(2) and (3)).

1b. Dependent claims 2-13

Claims 2-13 are dependent on claim 1 and as such also meet the requirements of the PCT with respect to novelty and inventive step.

2. Method claims 14 and 15

Method claims 14 and 15 are directed to the use of the device according to claim 1 for determining dielectric properties of an electrically conductive fluid and as such are also considered to meet the requirements of the PCT with respect to novelty and inventive step.

Re Item VII

Certain defects in the international application

The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

Re Item VIII

Certain observations on the international application

All features of claim 5 are already contained in claim 1. The claims therefore lack conciseness (Article 6 PCT).

- 4 -

the cavity were largely fixed as a function of the (fixed) frequency used.

Coupling of the microwave radiation into the cavity was achieved by an aerial, necessarily very large, which was itself exposed to the contents of the cavity - ie. to the flow.

The device unfortunately proved unsatisfactory due to factors including the size and expense of the magnetron used and its fixed frequency.

Despite these problems, it is recognised that measurement of the properties of the flow with regard to electromagnetic radiation is desirable since the properties of the three major constituents of the flow with regard to EM radiation are widely divergent, and hence easy to distinguish. This can be appreciated from the fact that the relative permittivity of the three constituents is approximately as follows:

- i. gas, $\epsilon_r = 1$;
- ii. crude oil, $\epsilon_r = 2.2$ (and this proves to be largely constant for all crude oils, despite variations in its component fractions);
- iii. water, $\epsilon_r = 81$.

The inventors have realised, and confirmed by experiment, that contrary to the hitherto conventional teaching, it is possible to efficiently couple radio and microwave radiation into a conductive medium within a resonant cavity provided that the cavity walls and the antenna used to output the radiation are electrically isolated from the medium itself.

In accordance with a first aspect of the present invention, there is an apparatus for determining dielectric properties of an electrically conductive fluid,

- 5 -

comprising an electromagnetically resonant cavity defined by an electrically conductive boundary; an inlet through which the fluid can be introduced into the cavity; an insulating layer whereby the cavity boundary is electrically isolated from fluid material within the cavity; an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from fluid material within the cavity; and means for detecting resultant electromagnetic radiation within the cavity.

Experiments carried out by the inventors have confirmed that using such an arrangement measurements of dielectric properties can be made without the need for the high power provided by a magnetron. The arrangement can serve as a dielectric permittivity sensor. Dielectric properties at a radio and microwave frequencies can be measured. In prototype arrangements, a simple loop aerial driven by an electronic oscillator has proved adequate by virtue of the efficient propagation of radiation through the fluid material made possible by the arrangement. As compared with the previous magnetron apparatus, this makes possible great simplification and cost saving, as well as other benefits which will become clear below.

The fluid in question may contain some solids, as typically does a flow of material in an oil extraction pipeline.

With regard to the frequency of radiation emitted into the cavity, it is considered that the present invention is particularly applicable to radio and microwave frequencies. The frequency range used is in part determined by the

- 9 -

In a preferred embodiment, the calculating means operates by calculating for a set of possible permutations of flow constituents the expected values of the measured properties and comparing these with the actual measured values to determine which permutation best matches the measured properties.

The calculating means may comprise a neural network, trained on experimental data, for determining expected quantities relating to the dielectric properties of the flow corresponding to the permutations of flow constituents. The quantities in question may be the frequencies of a selected resonant mode of the cavity.

In accordance with a third aspect of the present invention, there is a method of determining dielectric properties of an electrically conductive fluid comprising the steps of disposing the fluid material in or passing the fluid through an electromagnetically resonant cavity defined by an electrically conductive boundary which is electrically isolated from the fluid by an insulating layer, emitting electromagnetic radiation into the resonant cavity by means of an antenna which is electrically isolated from the fluid and detecting and analysing the resultant electromagnetic radiation within the resonant cavity.

Preferably, the method comprises varying the frequency of the emitted electromagnetic radiation and obtaining an indication of the amplitude of the resultant electromagnetic radiation within the resonant cavity. The frequency variation may be continuous. The results are preferably analysed to determine the position of at least one resonance peak within the cavity.

- 22 -

CLAIMS

1. An apparatus for determining dielectric properties of an electrically conductive fluid, comprising an electromagnetically resonant cavity defined by an electrically conductive boundary; an inlet through which the fluid can be introduced into the cavity; an insulating layer whereby the cavity boundary is electrically isolated from fluid material within the cavity; an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from fluid material within the cavity; and means for detecting resultant electromagnetic radiation within the cavity.
2. An apparatus as claimed in claim 1 wherein the drive electronics are adapted to operate at a range of frequencies such that a range of frequencies of electromagnetic radiation can be emitted to the cavity.
3. An apparatus as claimed in claim 2, wherein the frequency is continuously variable.
4. An apparatus as claimed in any preceding claim, wherein the antenna for emitting electromagnetic radiation into the fluid material is disposed within the resonant cavity such as to project into the fluid material, the antenna being provided with an insulating layer by which is it electrically isolated from the fluid material
5. An apparatus as claimed in any preceding claim, wherein the boundary of the resonant cavity comprises a conductive wall whose inner surface is covered by an internal insulating layer by which the wall is electrically isolated from the

- 23 -

fluid material within the cavity.

6. An apparatus as claimed in any preceding claim wherein the resonant cavity has an inlet and an outlet such that the fluid material can flow through the cavity.

7. An apparatus as claimed in any preceding claim wherein the means for detecting electromagnetic radiation within the cavity comprise a receiver antenna disposed within the resonant cavity and electrically isolated from the fluid material within the cavity.

8. An apparatus as claimed in any of claims 1 to 6 wherein the means for detecting electromagnetic energy within the cavity comprise electronics connected to the emitter antenna for measuring the voltage standing wave ratio.

9. A device for monitoring constituents of a fluid flow comprising an apparatus as claimed in any preceding claim.

10. A device as claimed in claim 9, further comprising measurement electronics for determining the frequency of a resonance peak corresponding to a selected resonant mode within the cavity.

11. A device as claimed in claim 9 or claim 10, further comprising means for measuring additional properties of the fluid flow and calculating means for determining, on the basis of the measured properties, the proportions of certain constituents of the flow.

12. A device as claimed in claim 11, wherein the calculating means operates by calculating for a set of possible permutations of flow constituents the

- 24 -

expected values of the measured properties and comparing these with the actual measured values to determine which permutation best matches the measured properties.

13. A device as claimed in claim 12, wherein the calculating means comprise a neural network, trained on experimental data, for determining expected quantities relating to the dielectric properties of the flow corresponding to the permutations of flow constituents.

14. A method of determining dielectric properties of an electrically conductive fluid comprising the steps of disposing the fluid material in or passing the fluid through an electromagnetically resonant cavity defined by an electrically conductive boundary which is electrically isolated from the fluid by an insulating layer, emitting electromagnetic radiation into the resonant cavity by means of an antenna which is electrically isolated from the fluid and detecting and analysing the resultant electromagnetic radiation within the resonant cavity.

15. A method as claimed in claim 14, comprising varying the frequency of the emitted electromagnetic radiation and obtaining an indication of the amplitude of the resultant electromagnetic radiation within the resonant cavity.

12/12

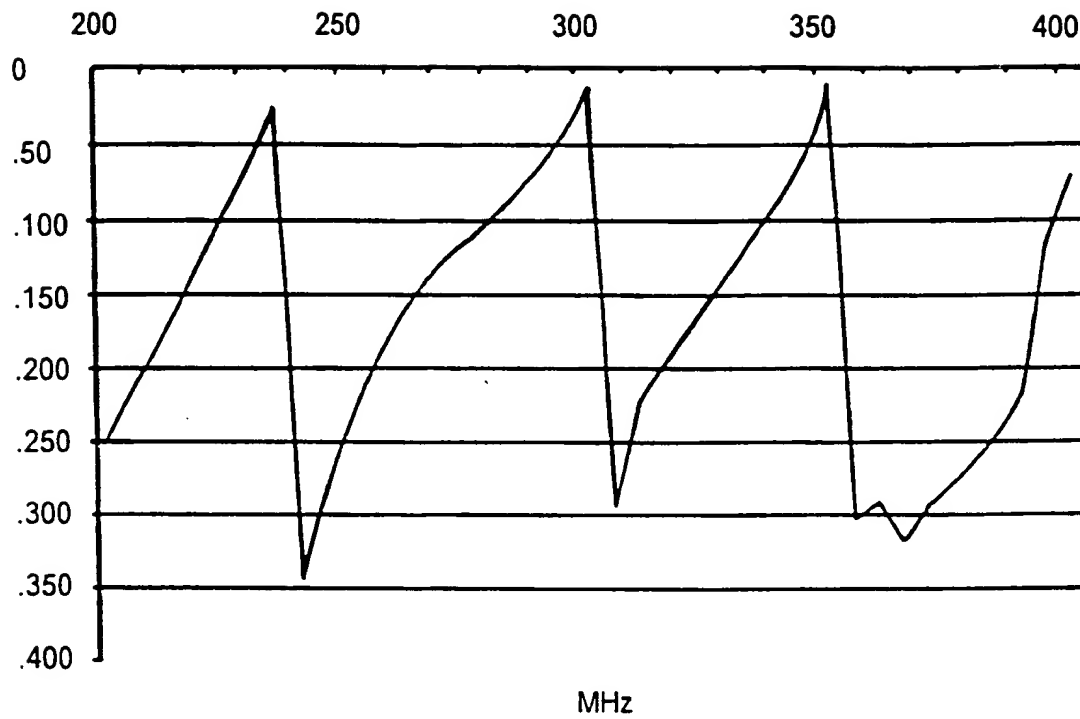


FIG.18.

Our Ref: DIH/KC

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20 March 2001

EUROPEAN PATENT OFFICE,
D-80298 Munchen,
Germany.

By Facsimile, Confd.
Registered Mail.

Dear Sirs,

Re: International Patent Application No: PCT/GB00/00168
THE UNIVERSITY OF LIVERPOOL ET AL
Our File No: P. 66650 WO

We refer to the First Written Opinion of the EPO in its capacity as IPEA to which a reply is due by the **20 March 2001**.

Pages 4, 5, 9, 22 and 24 of the text have been amended and retyped in response to the Examiner's comments and replacement sheets are attached in triplicate. We also attach a copy of the original pages showing in manuscript where they have been amended at this time.

Claim 1 has been amended so as to clearly distinguish the present invention from cited document D1. In particular, it has been made clear in claim 1 that the present apparatus includes an electrically resonant cavity defined by an electrically conductive boundary wall and an electrically insulating layer on those parts of the electrically conductive boundary wall defining the interior wall of the cavity, there being an inlet through which fluid can be introduced into the interior of the cavity. In contrast, in D1, the fluid is confined to the fluid line/pipe and does not effectively fill the cavity itself.

A brief discussion of D1 has been introduced on page 4 to comply with Rule 5.1(a)(ii) PCT.

With regard to the prior art referred to on page 3, line 9 - page 4, line 6, the Applicant is not aware of any specific document reflecting this prior art. The product in question was apparently made by a company called MFI which was taken over subsequently by Roxar ASA of Stravanger, Norway.

/2.....

EUROPEAN PATENT OFFICE

20 March 2001

The Examiner is correct that the decimal point in figure 18 should be minus signs and a corrected copy of figure 18 is attached in triplicate to replace that filed originally.

We now look forward to the issue of the International Preliminary Examination Report in due course.

Yours faithfully,

D.I. HUNTINGFORD
Professional Representative
Association No. 105

Encs: Replacement Pages (3);
Original sheets amended in manuscript (1); and
Amended figure 18 (3).

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p>(21) International Application Number: PCT/GB00/00168</p> <p>(22) International Filing Date: 24 January 2000 (24.01.00)</p> <p>(30) Priority Data: 9901304.7 22 January 1999 (22.01.99) GB</p> <p>(71) Applicant (for all designated States except US): THE UNIVERSITY OF LIVERPOOL [GB/GB]; Senate House, Abercromby Square, Liverpool L69 3BX (GB).</p> <p>(72) Inventors; and (75) Inventors/Applicants (for US only): LUCAS, James [GB/GB]; 12 Sunnigdale Drive, Blundellsands, Liverpool L23 7XA (GB). AL-SHAMMAA, Ahmed [GB/GB]; University of Liverpool, Dept. of Electrical Engineering & Electronics, Brownlow Hill, Liverpool L69 3GJ (GB).</p> <p>(74) Agent: W.P. THOMSON & CO.; Coopers Building, Church Street, Liverpool L1 3AB (GB).</p>		<p>(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published <i>With international search report.</i></p>
<p>(54) Title: APPARATUS AND METHOD FOR DETERMINING DIELECTRIC PROPERTIES OF AN ELECTRICALLY CONDUCTIVE FLUID</p> <div data-bbox="548 1087 1279 1591"></div> <p>(57) Abstract</p> <p>An apparatus is disclosed for determining dielectric properties of an electrically conductive fluid. The apparatus comprises an electromagnetically resonant cavity (2, 4, 6, 8) which may form part of a pipeline. An insulating layer (14) isolates the cavity's conductive wall from fluid within the cavity. An emitter antenna (10) and associated drive electronics are provided for emitting electromagnetic radiation into the cavity and the antenna is electrically isolated from fluid in the cavity. Means (12) are also provided for detecting resultant electromagnetic radiation in the cavity. The apparatus may be used in multi-phase metering.</p>		

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DESCRIPTION

APPARATUS AND METHOD FOR DETERMINING DIELECTRIC PROPERTIES OF AN ELECTRICALLY CONDUCTIVE FLUID

The present invention is concerned, in its broadest aspect, with an apparatus for and method of determining dielectric properties of an electrically conductive fluid. The invention is applicable in particular to the monitoring of multi-phase flows such as are found in oil pipelines.

The flow of material from an oil well typically contains not only crude oil but also other constituents, gas and water generally being the most significant of these. Other constituents such as sediment and algae are typically present in relatively small quantities. It is often necessary to monitor the relative proportions of the major constituents of the flow. One reason for this is to judge when a given well is becoming exhausted, signalled by a decline in the proportion of oil.

The traditional technique for this monitoring has involved separation of a sample of the material into its constituents, allowing straightforward single phase monitoring techniques to be used. While effective, processing systems based on this technique are somewhat inflexible in terms of their capability to handle fluctuating flow rates, varying water content and changes in the physical properties of the constituent fluids.

The technique also involves an undesirable time lag between extraction of the material at the well head and assessment of its constituents, not least because the assessment has to be made after separation of the materials on the rig itself -

ie. a considerable distance downstream of the well head.

For these reasons numerous projects have been undertaken to develop systems capable of real time multi-phase metering (MPM) - ie. real time measurement of the constituents of a sample (more specifically a flow) containing two or more constituents. The aim of such projects has been to arrive at a system capable of monitoring the proportions of oil, gas and water in an extraction pipeline. Such systems are now commercially available, but are not yet wholly satisfactory.

Such systems operate by monitoring bulk properties of the flow (without separating it into its constituent parts) and inferring from these the proportions of the major constituents of the flow - in the practical case of oil extraction, the major constituents are oil, gas and water.

To enable such inferences to be made, more than one property of the flow is monitored. Known systems typically measure the density of the flow material; its effect in attenuating gamma rays, and one other flow property such as its capacitance.

In tests, most existing systems prove to be capable of accurately measuring two phases - fluid and gas - but fail to achieve the desired accuracy in relation to flows having high water or low gas content when measuring three phase flows - oil, gas and water.

It is one of the objects of the present invention to make possible improved monitoring of three phase flows.

It is considered that in order to improve the accuracy of MPM devices it is important to monitor a third bulk property of the flow (aside from density and gamma ray attenuation) and that as yet no appropriate technique has been proposed for accurately monitoring an appropriate property.

The reason for the need for a third property measurement may be simply stated. It is necessary in a three phase flow to establish three unknown quantities - the proportions of the three constituents (eg. oil, gas and water). To this end, three simultaneous equations, one contributed by each monitored property, are required.

There has been at least one project which attempted to monitor, as the necessary third property, the effect of the flow on the propagation of electromagnetic radiation through it. This project faced an important problem. Flows emerging from an oil well head are electrically conductive due, among other factors, to their inclusion of salt water. Conventional technical teaching, based on the application of Maxwell's equations, is that electromagnetic radiation of wavelengths cannot be efficiently propagated through a conductive medium

The solution adopted by the previous project was to use high power electromagnetic radiation. To provide this power it was necessary to use a magnetron, which operated at a power of the order of 1 Kilowatt. and at a frequency of 2.46 GHz. Due to the use of a magnetron to supply this radiation, its frequency was non-adjustable. The radiation was input to a resonant cavity, through which the flow was passed. The cavity walls were conductive and were exposed to the flow itself. Due to the resonance requirement, the dimensions of

the cavity were largely fixed as a function of the (fixed) frequency used.

Coupling of the microwave radiation into the cavity was achieved by an aerial, necessarily very large, which was itself exposed to the contents of the cavity - ie. to the flow.

The device unfortunately proved unsatisfactory due to factors including the size and expense of the magnetron used and its fixed frequency.

Despite these problems, it is recognised that measurement of the properties of the flow with regard to electromagnetic radiation is desirable since the properties of the three major constituents of the flow with regard to EM radiation are widely divergent, and hence easy to distinguish. This can be appreciated from the fact that the relative permittivity of the three constituents is approximately as follows:

- i. gas, $\epsilon_r = 1$;
- ii. crude oil, $\epsilon_r = 2.2$ (and this proves to be largely constant for all crude oils, despite variations in its component fractions);
- iii. water, $\epsilon_r = 81$.

The inventors have realised, and confirmed by experiment, that contrary to the hitherto conventional teaching, it is possible to efficiently couple radio and microwave radiation into a conductive medium within a resonant cavity provided that the cavity walls and the antenna used to output the radiation are electrically isolated from the medium itself.

In accordance with a first aspect of the present invention, there is an apparatus for determining dielectric properties of an electrically conductive fluid,

- 5 -

comprising an electromagnetically resonant cavity defined by an electrically conductive boundary; an inlet through which the fluid can be introduced into the cavity; an insulating layer whereby the cavity boundary is electrically isolated from fluid material within the cavity; an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from fluid material within the cavity; and means for detecting resultant electromagnetic radiation within the cavity.

Experiments carried out by the inventors have confirmed that using such an arrangement measurements of dielectric properties can be made without the need for the high power provided by a magnetron. The arrangement can serve as a dielectric permittivity sensor. Dielectric properties at a radio and microwave frequencies can be measured. In prototype arrangements, a simple loop aerial driven by an electronic oscillator has proved adequate by virtue of the efficient propagation of radiation through the fluid material made possible by the arrangement. As compared with the previous magnetron apparatus, this makes possible great simplification and cost saving, as well as other benefits which will become clear below.

The fluid in question may contain some solids, as typically does a flow of material in an oil extraction pipeline.

With regard to the frequency of radiation emitted into the cavity, it is considered that the present invention is particularly applicable to radio and microwave frequencies. The frequency range used is in part determined by the

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resonance requirement and hence the cavity dimensions. It is currently believed potentially worthwhile to measure the response to frequencies of the order of 10 MHz to 10GHz. Research to date has usefully concentrated on the narrower range from approximately 100MHz to approximately 5GHz.

It is particularly preferred that the drive electronics are adapted to operate at a range of frequencies such that a range of frequencies of electromagnetic radiation can be emitted to the cavity. Preferably, the frequency is continuously variable.

This can be conveniently achieved in apparatus according to the present invention since the radiation does not need to be at the high power provided by the magnetron of the previous system.

In prototype arrangements embodying the present invention, a spectrum analyser has been used to drive a loop aerial at a continuously variable frequency. In this way, it becomes possible to measure the properties of the cavity and the material it contains throughout a chosen region of the electromagnetic spectrum.

The antenna for emitting electromagnetic radiation into the fluid material is preferably disposed within the resonant cavity such as to project into the fluid material, the antenna being provided with an insulating layer by which it is electrically isolated from the fluid material.

Such an arrangement provides for efficient coupling of the electromagnetic radiation into the fluid material.

The conductive boundary of the resonant cavity may comprise a conductive

- 7 -

wall whose inner surface is covered by an internal insulating layer by which the wall is electrically isolated from the fluid material within the cavity. The insulating layer may be a low loss dielectric. Ceramic can be used.

It is particularly preferred that the resonant cavity has an inlet and an outlet such that the fluid material can flow through the cavity. This makes it possible to monitor, continuously if required, the properties of a fluid flow.

In a currently preferred embodiment of the present invention, the means for detecting electromagnetic radiation within the cavity comprise a receiver antenna disposed within the resonant cavity and electrically isolated from the fluid material within the cavity.

Alternatively or additionally, the means for detecting electromagnetic radiation within the cavity may comprise electronics connected to the emitter antenna for measuring the voltage standing wave ratio. The effect is to provide an indication of the reflected power at the emitter antenna.

In accordance with a second aspect of the present invention, there is provided a device for monitoring the constituents of a fluid flow, the device comprising an apparatus according to the first embodiment of the present invention. Of particular importance is the case where the device is adapted for monitoring the constituents of a flow of material in an oil pipeline. Multi-phase metering can be carried out by such a device.

In such an embodiment, the resonant cavity may be formed by a portion of the pipeline. Preferably, the electrically conductive boundary defining the resonant

cavity comprises a conductive circumferential wall around the inside or outside of the pipeline. The boundary may additionally comprise conductive end walls disposed across the pipeline to functionally enclose the resonant cavity. It is not considered essential that these end walls be continuous - they may for example be formed by open wire grid or mesh, serving to form a functionally enclosed resonant electrical cavity while permitting flow of material through the pipeline. Alternatively, the cavity may be open ended. It is found that circular resonance modes persist even when the cavity is not enclosed.

The device may for example be installed in a pipeline close to the point of extraction, serving to monitor in real time the properties of the material being extracted.

It is particularly preferred that the device comprises measurement electronics for determining the frequency of a resonance peak corresponding to a selected resonant mode within the cavity.

As will be explained below, it has been found that the frequency of such a resonance peak is shifted according to the proportions of different materials in the fluid flow, and that the frequency provides information which can be used in determining, or at least estimating, the proportions of different materials in the flow.

The device preferably comprises means for measuring additional properties of the fluid flow and calculating means for determining, on the basis of the measured properties, the proportions of certain constituents of the flow. The additional properties measured may comprise absorption of gamma ray radiation and density.

In a preferred embodiment, the calculating means operates by calculating for a set of possible permutations of flow constituents the expected values of the measured properties and comparing these with the actual measured values to determine which permutation best matches the measured properties.

The calculating means may comprise a neural network, trained on experimental data, for determining expected quantities relating to the dielectric properties of the flow corresponding to the permutations of flow constituents. The quantities in question may be the frequencies of a selected resonant mode of the cavity.

In accordance with a third aspect of the present invention, there is a method of determining dielectric properties of an electrically conductive fluid comprising the steps of disposing the fluid material in or passing the fluid through an electromagnetically resonant cavity defined by an electrically conductive boundary which is electrically isolated from the fluid by an insulating layer, emitting electromagnetic radiation into the resonant cavity by means of an antenna which is electrically isolated from the fluid and detecting and analysing the resultant electromagnetic radiation within the resonant cavity.

Preferably, the method comprises varying the frequency of the emitted electromagnetic radiation and obtaining an indication of the amplitude of the resultant electromagnetic radiation within the resonant cavity. The frequency variation may be continuous. The results are preferably analysed to determine the position of at least one resonance peak within the cavity.

Detection of electromagnetic radiation within the resonant cavity may, in a preferred embodiment of the method according to the present invention, be by means of a receiver antenna itself electrically isolated from the fluid material. Alternatively or additionally it may be by analysis of the voltage standing wave ratio in the emitter antenna.

In a particularly preferred version of the method according to the present invention, the determined dielectric properties are utilised to monitor the constituents of a fluid flow passed through the resonant cavity.

Preferably such a method comprises additionally monitoring further properties of the fluid flow. Gamma ray radiation absorption and density are suitable properties.

The method preferably comprises calculating for a set of possible proportions of flow constituents the expected values of the measured properties and comparing these with the measured values to determine which best matches the measured properties.

Specific embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a longitudinal section through a prototype resonant cavity apparatus embodying the present invention;

Figure 2 is a graph showing the amplitude (measured in millivolts) of a signal detected by an aerial within the cavity against the frequency (measured in megahertz) of a microwave signal input to the cavity, in the case where the cavity

- 11 -

is filled with gas;

Figure 3 corresponds to Figure 2 but represents the case where the cavity is filled with oil;

Figure 4 corresponds to Figure 2 but represents the case where the cavity is filled with water;

Figure 5 is a graph having the same axes as Figure 2 (albeit with different ranges) on which signal amplitudes corresponding to cavities filled with gas, oil and water are juxtaposed;

Figure 6 is a table of observed fundamental resonance frequencies of the cavity corresponding to a range of cavity contents;

Figure 7 is a graph of the results for oil/gas mixtures tabulated in Figure 6 showing resonant frequency in MHz on the vertical axis against, on the horizontal axis, the percentage of oil (the upper row of figures along this axis) and the percentage of gas (the lower row of figures on this axis);

Figure 8 corresponds to Figure 7 except that the results shown are for water/gas mixtures, the percentage of water being indicated by the upper row of figures on the horizontal axis and the percentage of gas being indicated by the lower row of figures;

Figure 9 corresponds to Figure 7 except that the results shown are for water/oil mixtures, the percentage of water being indicated by the upper row of figures along the horizontal axis and the percentage of oil being indicated by the lower row of figures;

Figure 10 corresponds to Figure 7 except that the results shown are for a range of admixtures of gas with an equal volumetric mixture of oil and water, the percentage of gas being indicated by the upper row of figures along the horizontal axis and the percentage of oil/water being indicated by the lower row of figures;

Figure 11 is a graph showing four plots of detected signal amplitude variation with frequency for a mixture of water and air whose relative volumetric proportions were fixed throughout, each plot corresponding to a different rate of flow of the mixture through the apparatus;

Figure 12 is a graph showing how the detected signal amplitude (in volts on the vertical axis) is altered by an admixture of sand within the cavity over a range of frequencies;

Figure 13 illustrates elements of a neural network for use in an embodiment of the present invention;

Figure 14 shows the inputs to, and outputs from, the neural network during its training;

Figure 15 is a block diagram of a system utilising the neural network to infer the proportions of the constituents of a flow through the microwave cavity;

Figure 16 is a longitudinal section through a resonant cavity apparatus embodying the present invention for use in an oil pipeline;

Figure 17 is a graph of voltage standing wave ratio (VSWR) against frequency (MHz) at the transmitter antenna of an apparatus embodying the present invention for cavities filled with oil, gas and water, values for oil being indicated

- 13 -

by a solid triangle, values for water being indicated by a solid square and values for gas being indicated by a phantom triangle; and

Figure 18 is a graph of frequency (in Mhz on the horizontal axis) against phase shift (in degrees on the vertical axis).

The prototype apparatus illustrated in Fig. 1 has been used for proving the feasibility of the present invention. The apparatus comprises a cylindrical microwave cavity defined by copper side and end walls, 2, 4 and having an axial inlet 6 and outlet 8 by means of which flow material can be passed through the cavity. The cavity had, in this prototype device, a length of 158mm and a diameter of 189mm. There is however scope for variation of the shape and dimensions of the cavity. In the experimental arrangement illustrated, a pump (not seen) is used to circulate the test medium and so provide a flow.

Within the cavity is a first loop aerial 10 serving as a microwave transmitter and a second loop aerial 12 serving as a microwave receiver.

An important feature of the apparatus is an electrical insulation layer 14 provided on the interior of the cavity walls to electrically isolate the cavity walls from the cavity's interior. Further insulation layers 16, 18 are provided on the transmitter aerial 10 and the receiver aerial 12, which are thereby also electrically isolated from the interior of the cavity.

Experiments carried out using the prototype apparatus have confirmed that by virtue of the electrical isolation of the cavity and aerals from the cavity contents, it becomes possible to efficiently couple electromagnetic radiation into

the medium and to detect the radiation, even where the power of the emitted radiation is low. In the prototype apparatus, both aerials are connected to a spectrum analyzer used both to drive the transmitter aerial 10 at a range of test frequencies and to detect and store the corresponding signal amplitudes detected by the receiver aerial 12. In this way, it is possible to measure and plot the full microwave spectrum of the cavity.

Figs. 2, 3 and 4 are the observed spectra for cavities filled with gas, oil and water respectively (established during preliminary testing of the apparatus) and show clear peaks corresponding to resonant modes of oscillation of the microwaves within the cavity.

The microwave cavity has been theoretically modelled using solutions to Maxwell's equations to clearly identify the modes of the resonances set up in the cavity. Each mode is either TE_{mnl} or TM_{mnl} where m represents the circumferential variations in the field pattern, n represents the radial variations of the field pattern and l represents the length variations of the field pattern. Some of the identified modes obtained by matching up the theory to the experimental measurements are marked on Fig. 2.

There is preferential excitation of the TE modes under the illustrated experimental arrangement.

Comparing the spectrum for an oil filled cavity (Fig. 3) with that of a gas filled cavity (Fig. 2) it is found that there is an observable shift in the resonance peaks of approximately 400MHz, the resonant frequencies being lower when oil

is present. This is due to the higher dielectric constant of oil (2.2) compared with gas (1.0).

When the cavity is filled with water, an extreme shift of resonant frequencies occurs due to the high dielectric constant of water (approximately 80).

The effect of the cavity contents on the positions of the resonance peaks is illustrated most clearly in Fig. 5, on which the three curves are superimposed, the left-most curve corresponding to a water filled cavity, the centre curve corresponding to an oil filled cavity and the right-most curve corresponding to a gas filled cavity. On each curve, the label R denotes the cavity's fundamental resonant mode. Its frequency shift is clearly apparent.

Figs. 2 to 5 concern the simple cases in which only one material is present within the cavity. The inventors have however studied the more complicated case of a mixed flow, and in particular measured the effect of a range of mixed flows on the frequency of the fundamental (lowest frequency) resonant mode within the cavity.

In Fig. 6, the experimentally observed frequency of the fundamental mode is tabulated against a range of proportions of gas, water and oil. The trends are more easily appreciated with reference to Figs. 7 to 10, which show:

Fig. 7: the variation of the frequency of the fundamental mode for an oil/gas combination;

Fig. 8: the variation of the frequency of the fundamental mode for a water/gas combination;

Fig. 9: the variation of the frequency of the fundamental mode for a water/oil combination; and

Fig. 10: the variation of the frequency of the fundamental mode for gas with a 50:50 admixture of oil and water.

The graphs are monotonic and give only a single frequency for a given mixture, under consistent conditions.

The pattern of flow within the cavity is dependent not only on the composition of the flow but also on other factors including its speed. In particular, the number and size of gas bubbles may be affected. The pattern of gas bubbles in an oil pipeline can also, for example, be affected by an expanding gas fraction at the well head, tending to generate enlarged gas "slugs".

It was anticipated that varying bubble sizes resulting from varying flow rates and other factors would cause a corresponding variation in the form of the observed microwave spectrum, but it has emerged from experiments carried out by the inventors that the spectrum depends mainly on the volumetric composition of the flow and not on the gas bubble size or speed of flow. This is clearly advantageous given the goal of assessment of the constituents of a flow whose speed and flow pattern may vary. However flow homogenisation can be used to remove effects relating to flow pattern.

The relevant observations are graphed in Fig. 11, on which are shown four spectra corresponding to four different rates of flow of a water/gas mixture (the volumetric proportions of which were fixed at 80% water and 20% air) through the

- 17 -

prototype apparatus, including the base of zero flow - ie. a static mixture. Even when the flow is stopped, so that the gas forms a single body above the liquid, it is found that the spectrum is largely unchanged.

To assess the possible effect of further constituents in the flow (in addition to oil, gas and water) experiments have been carried out in which a proportion of sand is added. The results are graphed in Fig 12, where curve A was obtained when the cavity contained only water while curve B was obtained using 95 % water with 5 % sand. The dielectric constant of sand is approximately 4.5, and the sand therefore caused a detectable shift in the first resonance peak.

Temperature dependence of the resonance peaks has been studied using a cavity filled with water and pumped at a constant speed. As the temperature is increased it is found that the frequency of the first peak increases. The effect is caused by a decrease in the value of the dielectric constant ϵ with increasing temperature. The velocity of microwaves in water depends on the square root of the relative permittivity as follows.

$$v = \frac{C}{\sqrt{\epsilon}}$$

The frequency within the cavity is proportional to the velocity of the microwave so that if the cavity resonates at 150MHz at 30°C, the same cavity will resonate at 161MHz at 60°C.

As an aid to the automation of the sensor system the phase relationship between the input and output signals for the cavity has been investigated. The

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input signal was provided by a Signal Generator (frequency range 10kHz - 1GHz) and the output signal was recorded on a Signal Analyser (frequency range up to 10GHz). The phase delay is found to vary between 0 and -360° and is periodic when higher phase delays are present at the higher frequencies.

Results given in Figure 17 show the periodic structure observed for measurements in the cavity system for mixtures of oil and water. The phase shift is periodic and represents the resonance structure found within the amplitude signals at the receiver. If the resonance is modelled on a fourth order linear differential equation then the resonance should occur when the phase shift is -180° between the input and output signals.

The conclusion to this experiment is that phase may be used to indicate the presence of a resonance frequency. This technique is useful to obtain the position of the first resonance frequency of the system and therefore provides consistent training data for the neural network. When using the sensor system the position of the resonance frequency of an unknown mixture can be obtained by recording the frequency when the phase shift is -180° from the first phase resonance curve.

The overall effect of all of the abovedescribed experiments is to confirm that the microwave spectrum observed by use of apparatus of the general type illustrated in Fig. 1 can provide useful information relevant to the determination of the constitution of a multi-phase flow.

It is of course necessary, in a practical situation, to be able to infer from measured data concerning the flow (including the microwave spectrum) the

- 19 -

proportions of the flow constituents. In the system described herein, this is achieved by means of a Neural Network.

The Neural Network of the existing system has been implemented using the C++ language. The currently preferred one hidden layer Network is illustrated in Fig. 13 and is specified in terms of input, number of nodes in the hidden layers and outputs. The weighting coefficients W_{mn} and K_{np} for each node are calculated.

A two layered backpropagation (MLP) network was used. A logsig function was used for each of the layers because it constrains the outputs to positive values only. The number of hidden layers was chosen arbitrarily at first and then modified to decrease training time/accuracy for the network. It was also decided to use a backpropagation network with momentum and adaptive learning. These functions allow the Sum Squared Error to escape from "local minima" which occur in some of the error surface graphs.

Without this "momentum", the network may become stuck in local minima and will not train to the actual minimum.

In known manner, the Neural Network is trained by reference to a body of experimental data. The various parameters input to the Network NN during training are seen in Fig. 14 and are: percentage of oil O, percentage of water W, percentage of gas G, temperature T, water conductivity σ , flow pattern FP and frequency F. Fluid pressure may additionally be calculated and input to the Network, since the volume of gas - and hence the microwave properties - are

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pressure dependent.

The trained Network is then utilised within a predictive algorithm whose functional elements are illustrated in Fig. 15. Because of the high speed of the computer used to implement the algorithm, it is possible to scan all expected combinations of oil, gas and water within the flow. The combinations are input, as seen toward the left of the drawing, to the Neural Network NN which provides a corresponding predicted value f for the frequency of the cavity's fundamental mode of oscillation.

The combinations are also input to functional units A1, A2 which calculate, analytically, the corresponding values of the flow density ρ and the absorption of gamma rays, α .

The resulting derived values for f , α and ρ are then output to a comparator C which also receives the measured values f_m , σ_m , α_m of the same parameters.

The comparator selects the best fit of the derived values for f , α and ρ to the observed values of the same parameters, and on this basis makes a determination of the oil, gas and water proportions.

The arrangement illustrated in Fig. 1 has been used in the laboratory for testing purposes. Fig. 16 illustrates schematically an arrangement intended for incorporation in an oil extraction pipeline. The cylindrical pipeline wall is seen at 30, the direction of flow being indicated by arrow 32. The resonant electromagnetic cavity is defined by a conductive liner 34 on the interior of the pipeline wall, the ends of the liner being provided with conductive grids 36 which

allow flow of material while still defining the extent of the cavity. A microwave transmitter 38 and a microwave receiver 40 are again provided, and as in the Fig. 1 embodiment the "walls" of the cavity, the emitter and the receiver are electrically insulated from the contents of the cavity.

It is possible to dispense with the grids 36, so that the liner 34 alone defines the resonant cavity, in which case certain modes of oscillation are lost but some remain and may be measured as before.

The embodiments of the invention illustrated in Figs. 1 and 16 utilise a receiver separate from the emitter, thereby measuring EM microwave energy input to the cavity as a function of frequency.

An alternative is to observe the reflected power at the transmitting antenna. This is observed by measuring the antenna's voltage standing wave ratio (VSWR). This has been done experimentally. A summary of the results taken separately in oil, gas and water are given in Fig. 17. At the lower frequencies the VSWR is sensitive to the presence of water, at medium frequencies it is sensitive to the presence of oil whilst only at high frequencies is the VSWR sensitive to the presence of gas. It is believed that the VSWR may be used as a rough indicator of the mixture composition.

CLAIMS

1. An apparatus for determining dielectric properties of an electrically conductive fluid, comprising an electromagnetically resonant cavity defined by an electrically conductive boundary; an inlet through which the fluid can be introduced into the cavity; an insulating layer whereby the cavity boundary is electrically isolated from fluid material within the cavity; an emitter antenna and associated drive electronics for emitting electromagnetic radiation to the cavity, the emitter antenna being electrically isolated from fluid material within the cavity; and means for detecting resultant electromagnetic radiation within the cavity.

2. An apparatus as claimed in claim 1 wherein the drive electronics are adapted to operate at a range of frequencies such that a range of frequencies of electromagnetic radiation can be emitted to the cavity.

3. An apparatus as claimed in claim 2, wherein the frequency is continuously variable.

4. An apparatus as claimed in any preceding claim, wherein the antenna for emitting electromagnetic radiation into the fluid material is disposed within the resonant cavity such as to project into the fluid material, the antenna being provided with an insulating layer by which is it electrically isolated from the fluid material

5. An apparatus as claimed in any preceding claim, wherein the boundary of the resonant cavity comprises a conductive wall whose inner surface is covered by an internal insulating layer by which the wall is electrically isolated from the

fluid material within the cavity.

6. An apparatus as claimed in any preceding claim wherein the resonant cavity has an inlet and an outlet such that the fluid material can flow through the cavity.

7. An apparatus as claimed in any preceding claim wherein the means for detecting electromagnetic radiation within the cavity comprise a receiver antenna disposed within the resonant cavity and electrically isolated from the fluid material within the cavity.

8. An apparatus as claimed in any of claims 1 to 6 wherein the means for detecting electromagnetic energy within the cavity comprise electronics connected to the emitter antenna for measuring the voltage standing wave ratio.

9. A device for monitoring constituents of a fluid flow comprising an apparatus as claimed in any preceding claim.

10. A device as claimed in claim 9, further comprising measurement electronics for determining the frequency of a resonance peak corresponding to a selected resonant mode within the cavity.

11. A device as claimed in claim 9 or claim 10, further comprising means for measuring additional properties of the fluid flow and calculating means for determining, on the basis of the measured properties, the proportions of certain constituents of the flow.

12. A device as claimed in claim 11, wherein the calculating means operates by calculating for a set of possible permutations of flow constituents the

expected values of the measured properties and comparing these with the actual measured values to determine which permutation best matches the measured properties.

13. A device as claimed in claim 12, wherein the calculating means comprise a neural network, trained on experimental data, for determining expected quantities relating to the dielectric properties of the flow corresponding to the permutations of flow constituents.

14. A method of determining dielectric properties of an electrically conductive fluid comprising the steps of disposing the fluid material in or passing the fluid through an electromagnetically resonant cavity defined by an electrically conductive boundary which is electrically isolated from the fluid by an insulating layer, emitting electromagnetic radiation into the resonant cavity by means of an antenna which is electrically isolated from the fluid and detecting and analysing the resultant electromagnetic radiation within the resonant cavity.

15. A method as claimed in claim 14, comprising varying the frequency of the emitted electromagnetic radiation and obtaining an indication of the amplitude of the resultant electromagnetic radiation within the resonant cavity.

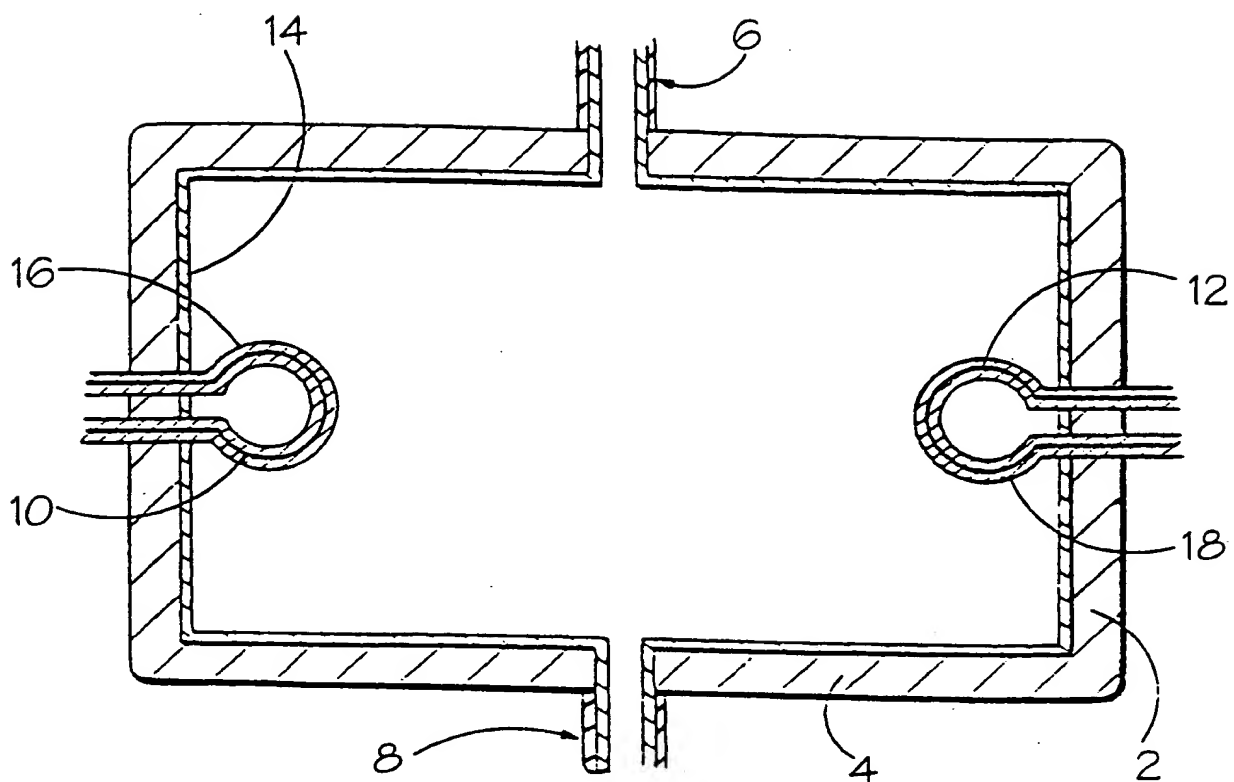


FIG.1.

2/12

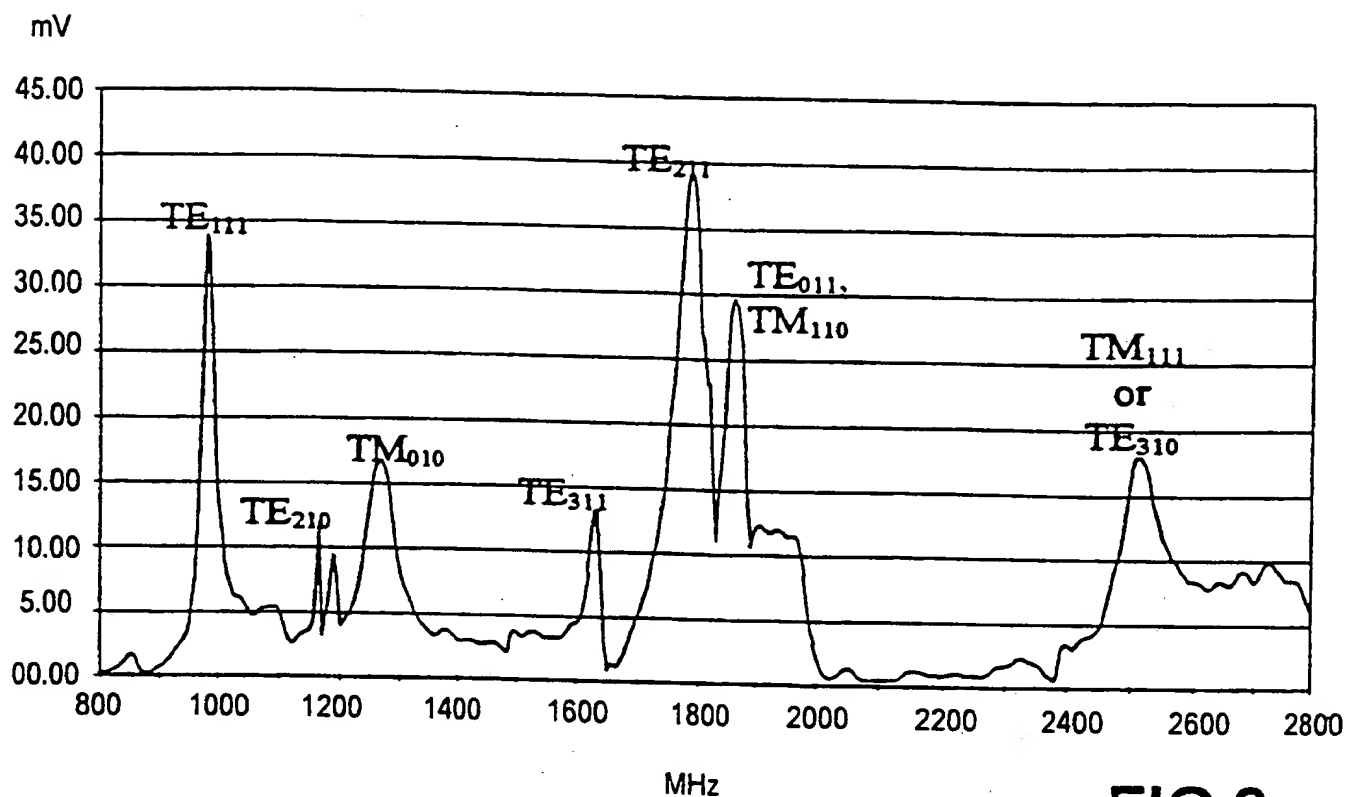


FIG. 2.

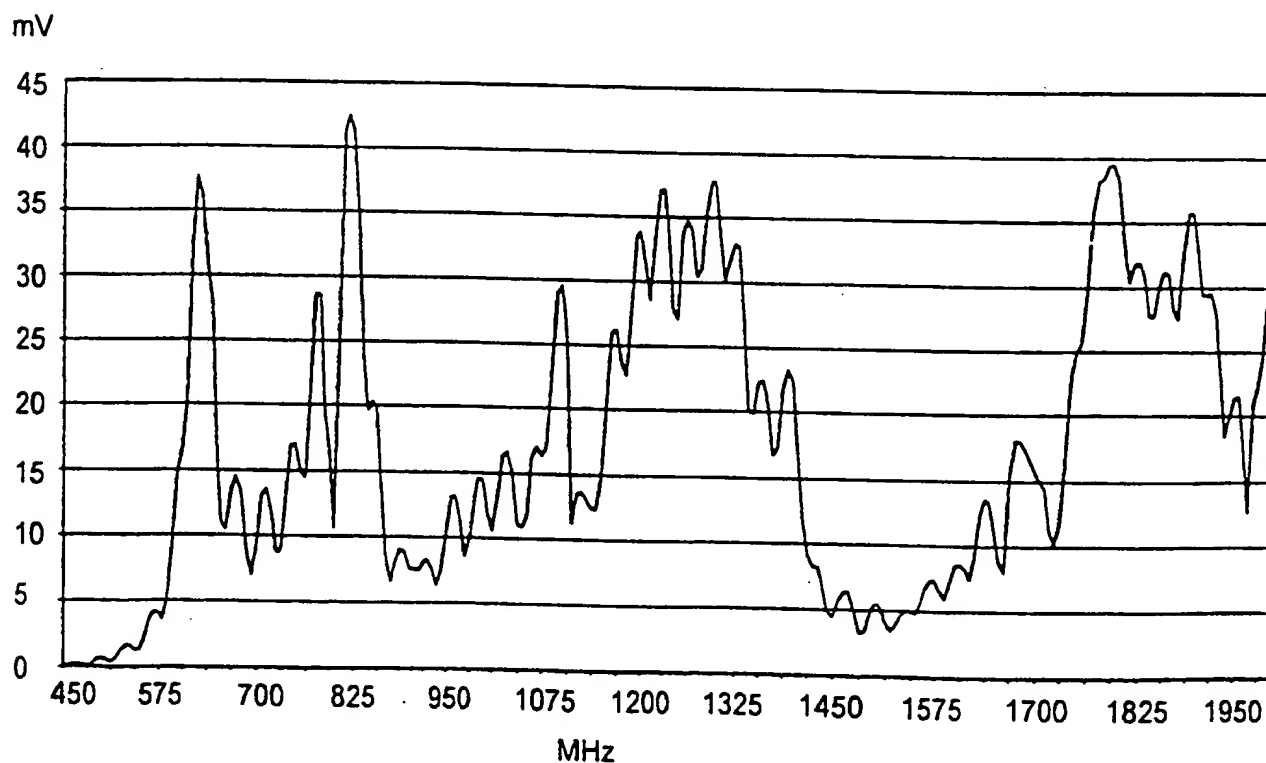


FIG. 3.

3/12

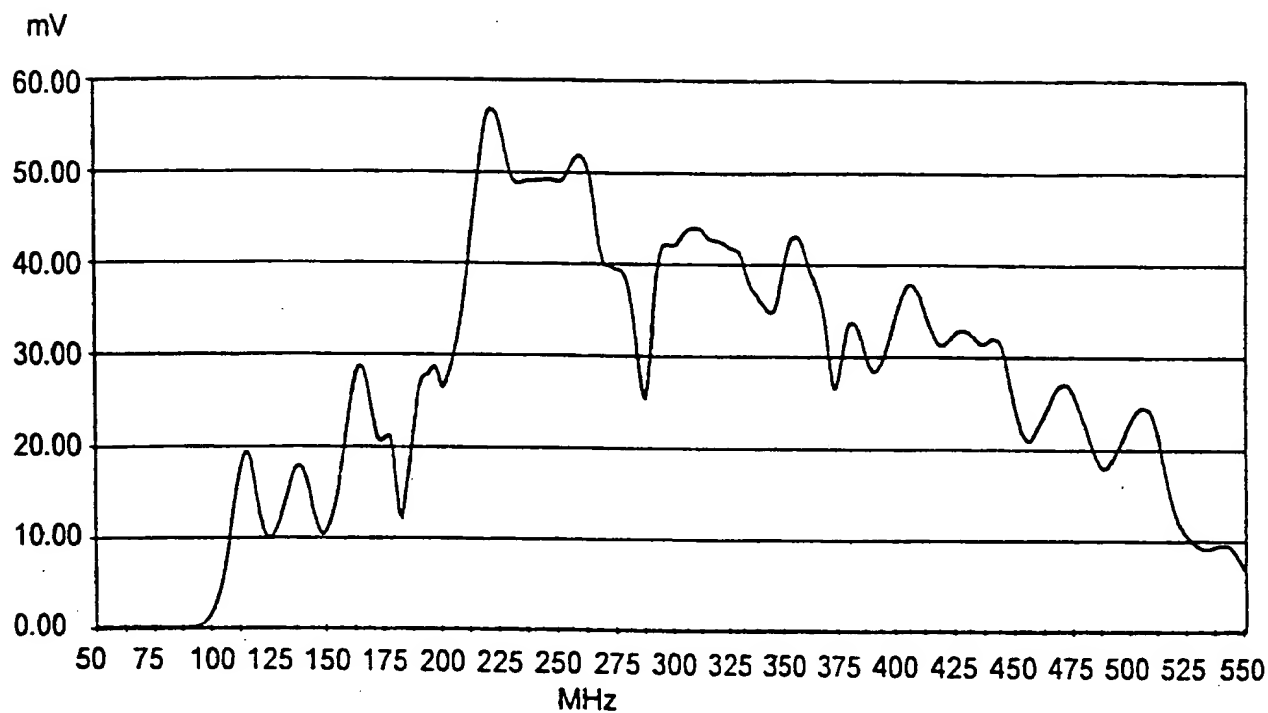


FIG. 4.

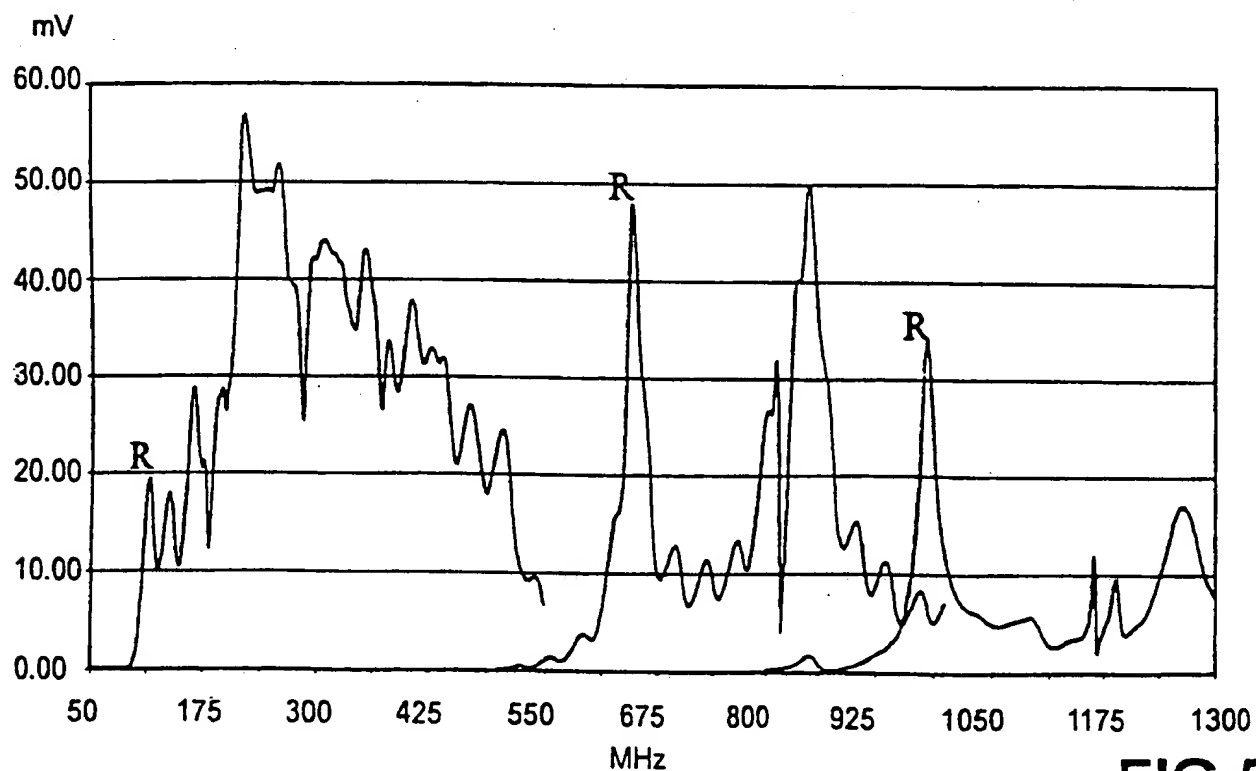


FIG. 5.

4/12

%Gas	%Oil	%Water	Freq (MHz)
100	0	0	981
90	10	0	977
80	20	0	952
70	30	0	851
60	40	0	802
50	50	0	759
40	60	0	723
30	70	0	707
20	80	0	682
10	90	0	663
0	100	0	649
100	0	0	981
90	0	10	938
80	0	20	610
70	0	30	431
60	0	40	365
50	0	50	305
40	0	60	240
30	0	70	190
20	0	80	170
10	0	90	143
0	0	100	118
0	100	0	640
0	90	10	423
0	80	20	335
0	70	30	277
0	60	40	236
0	50	50	205
0	40	60	159
0	30	70	148
0	20	80	131
0	10	90	126
0	0	100	118
0	50	50	205
10	45	45	231
20	40	40	257
30	35	35	320
40	30	30	372
50	25	25	440
60	20	20	530
70	15	15	600
80	10	10	755
90	5	5	915
100	0	0	981

FIG.6.

5/12

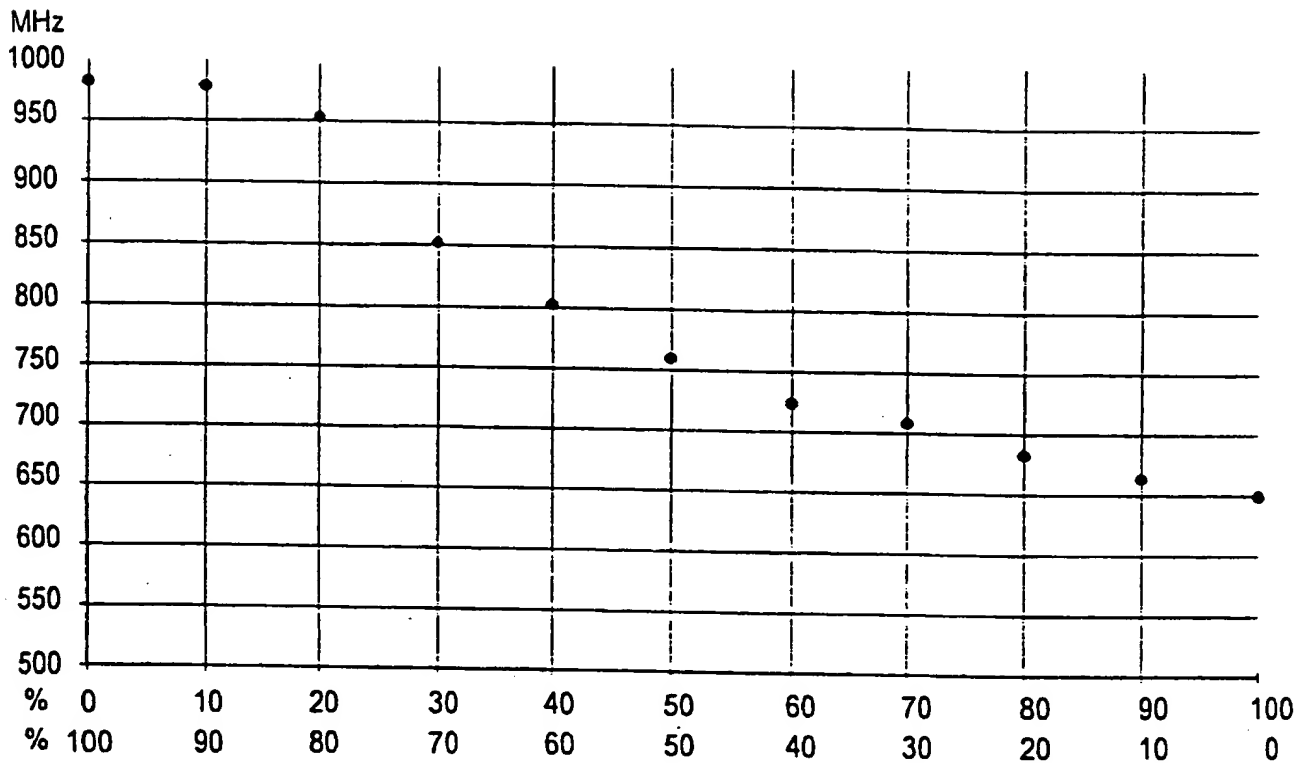


FIG. 7.

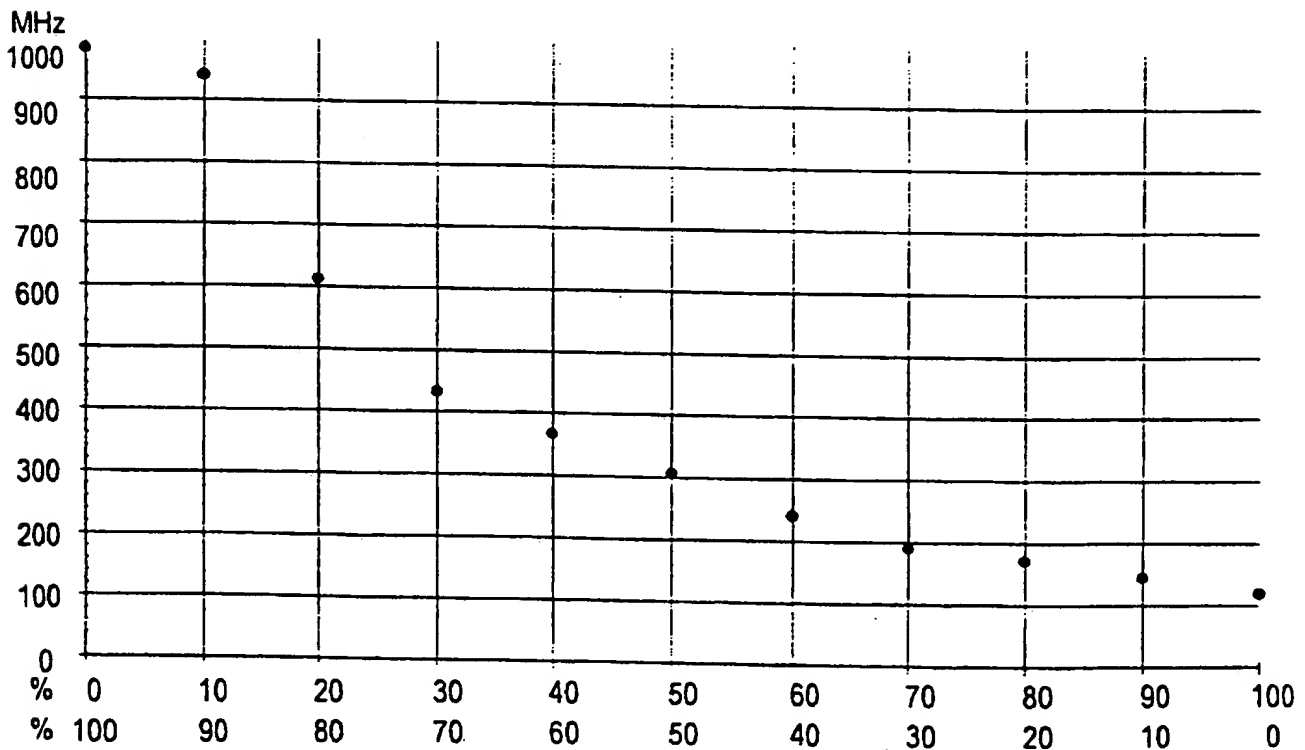


FIG. 8.

6/12

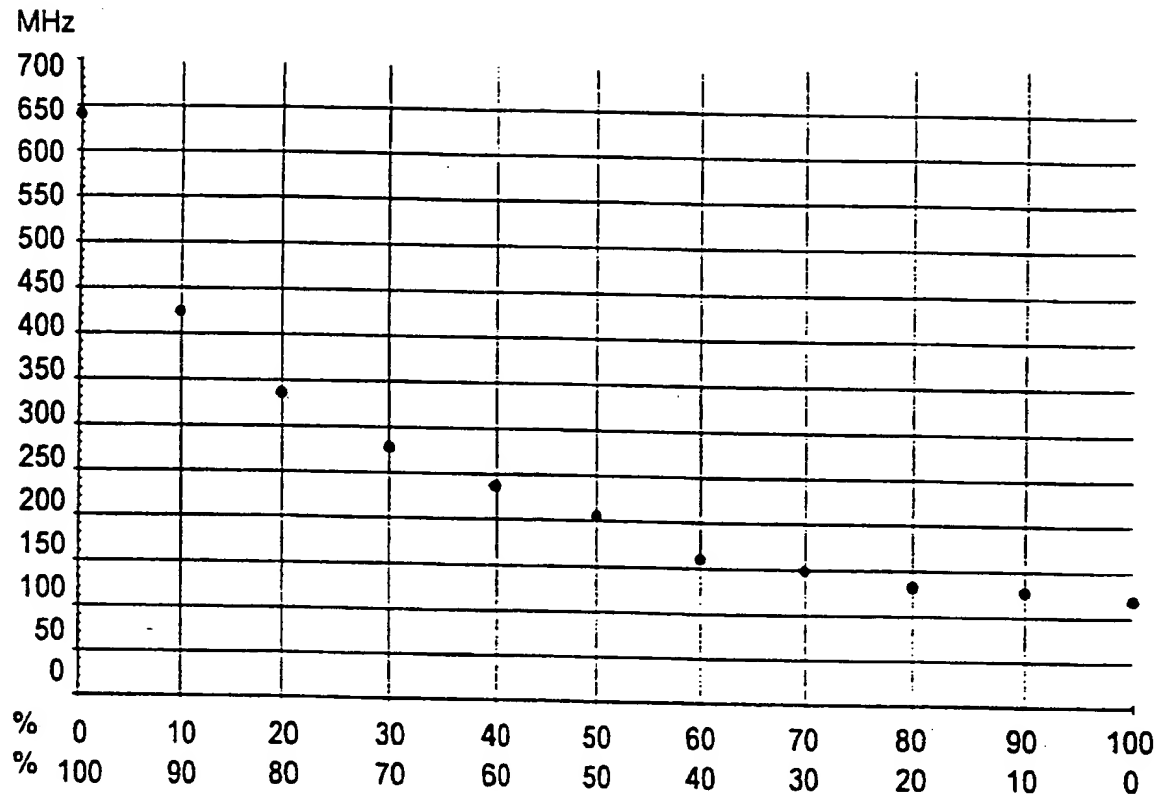


FIG.9.

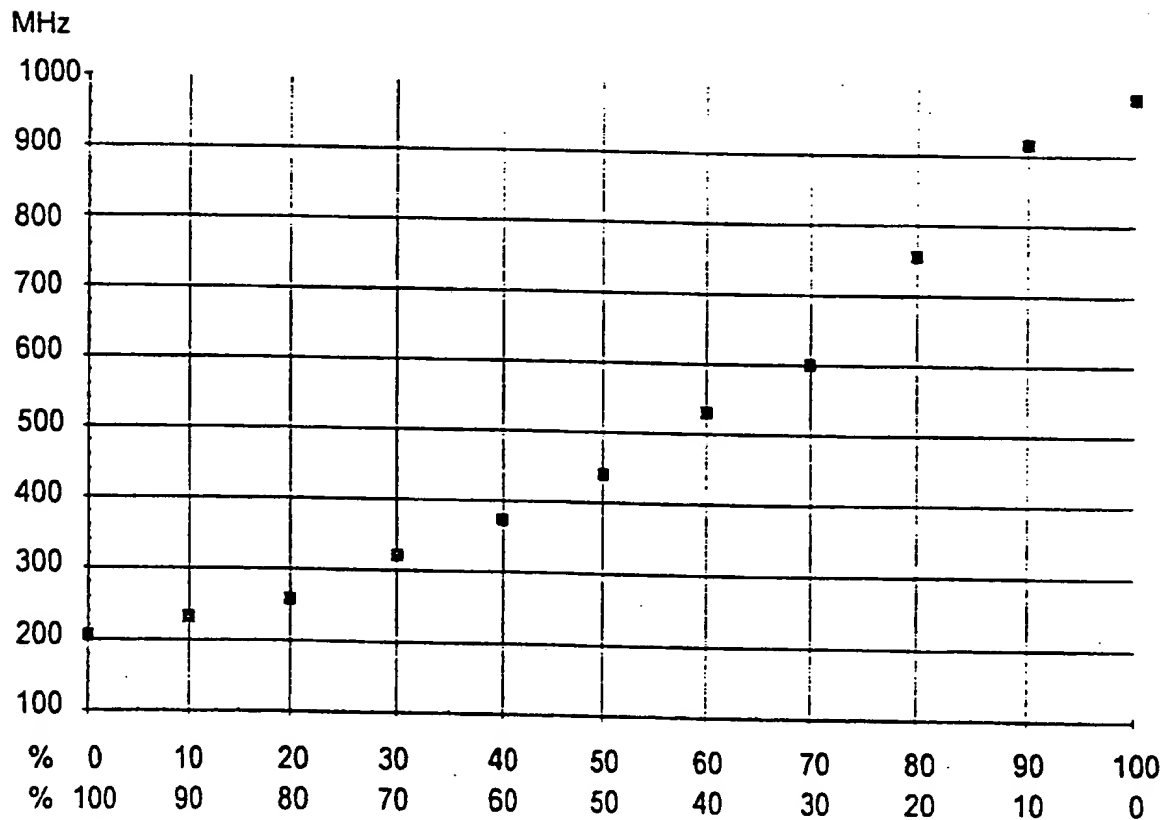


FIG.10.

7/12

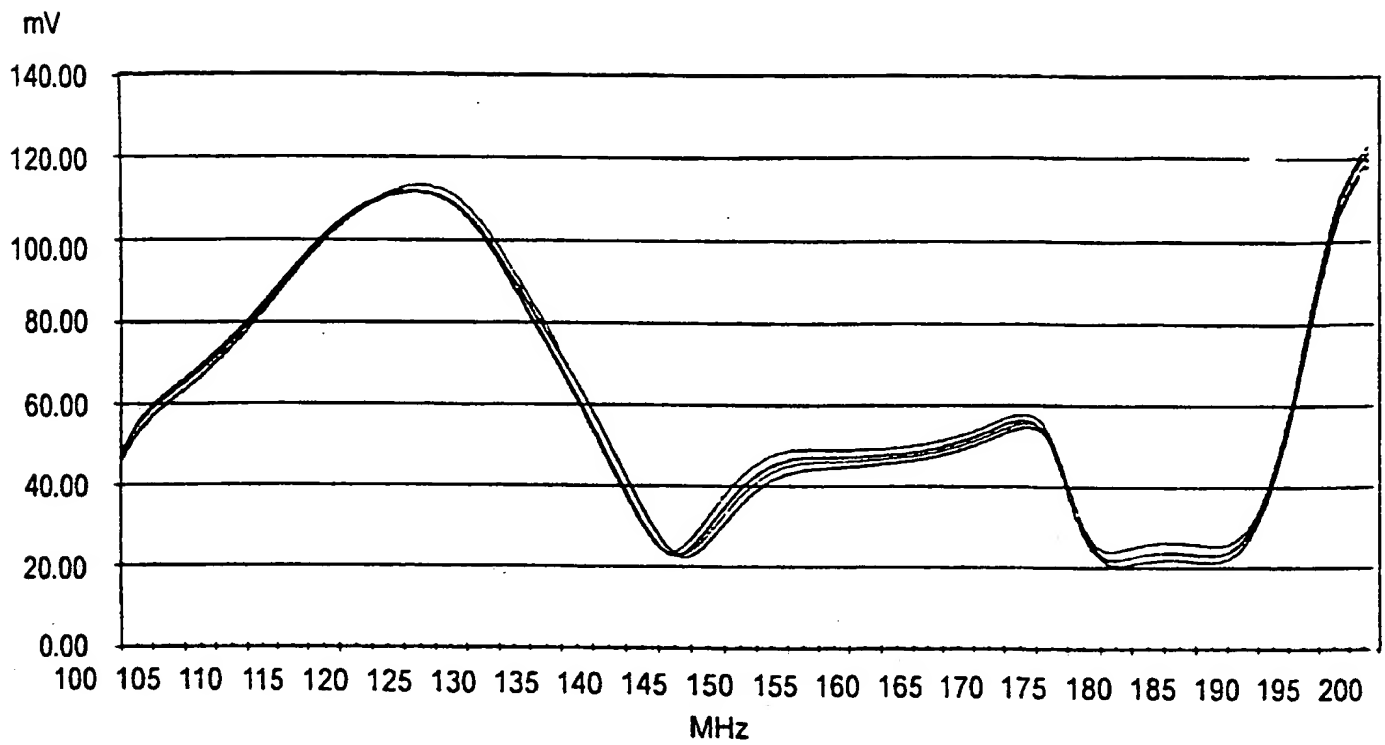


FIG.11.

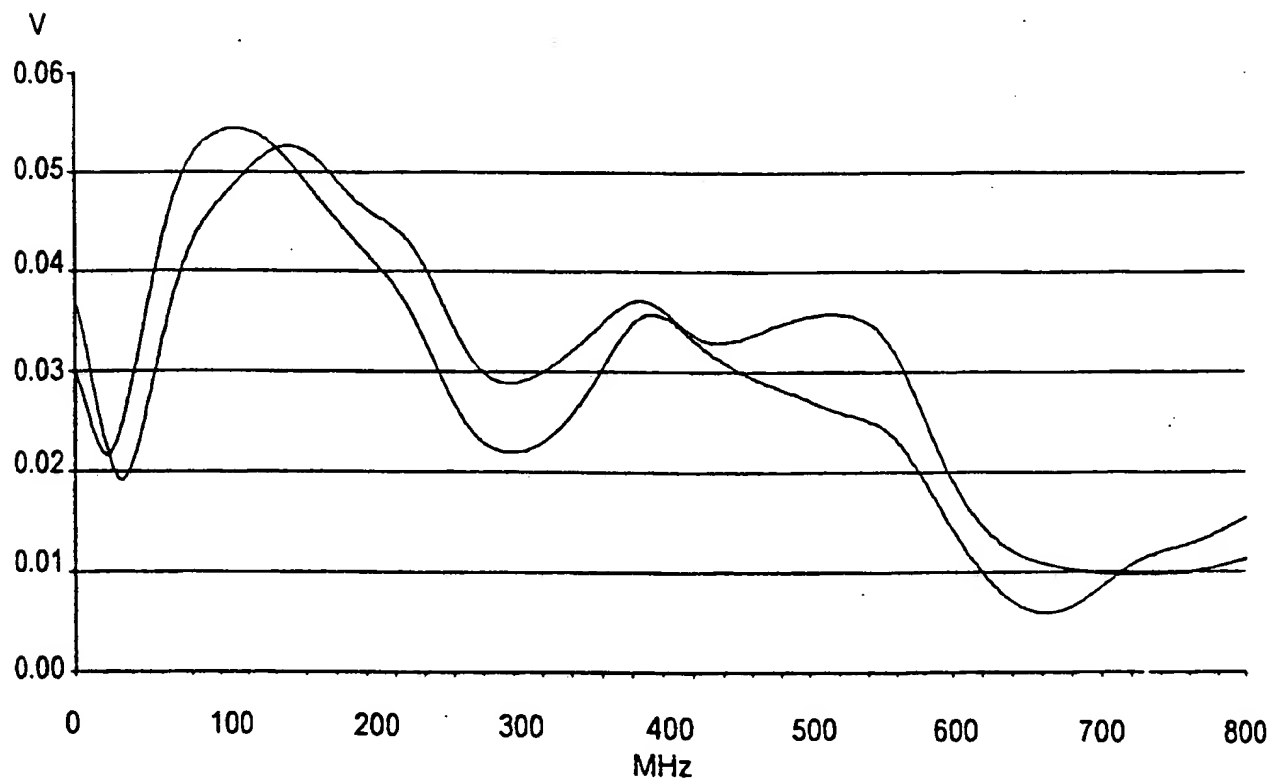


FIG.12.

8/12

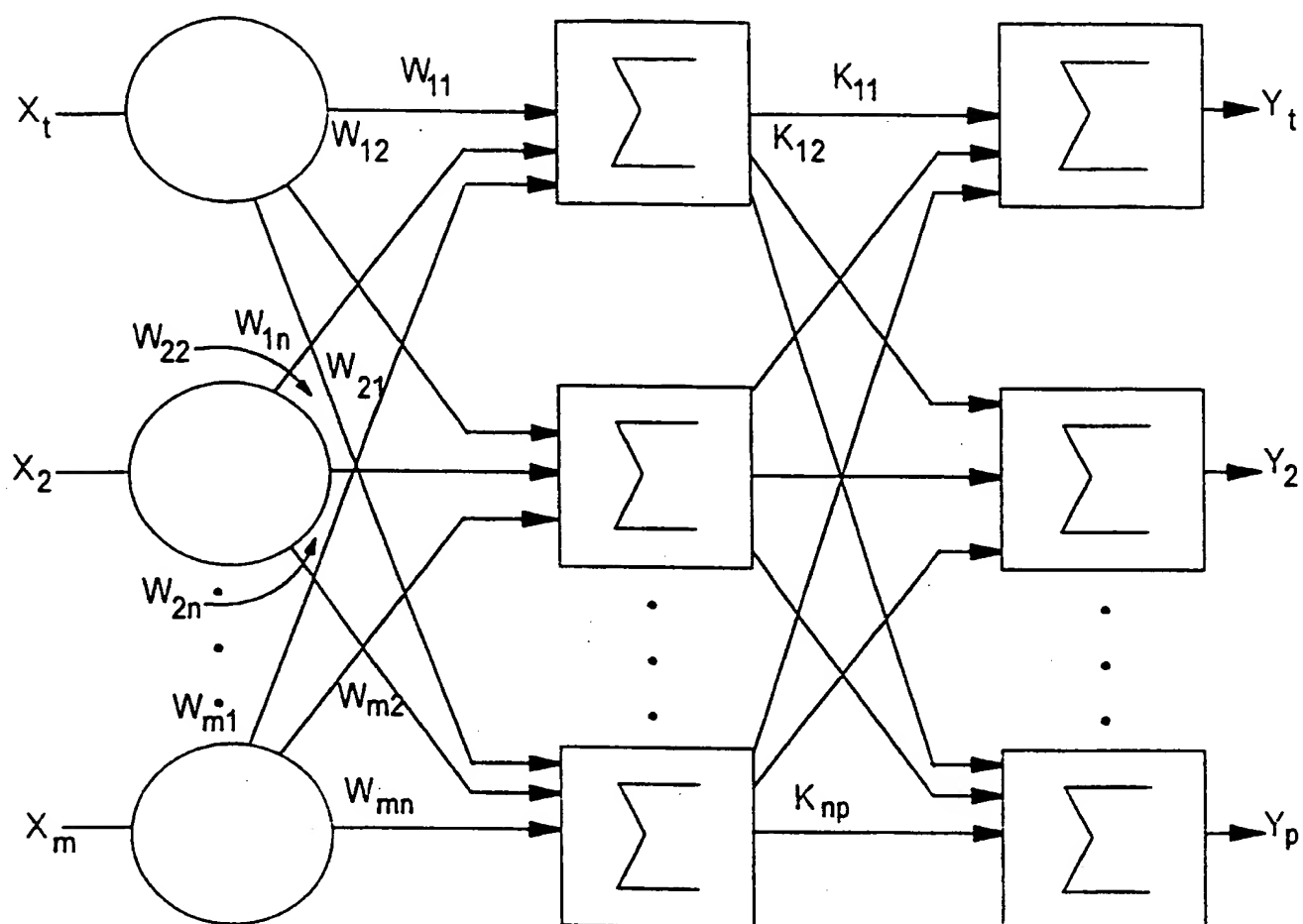


FIG.13.

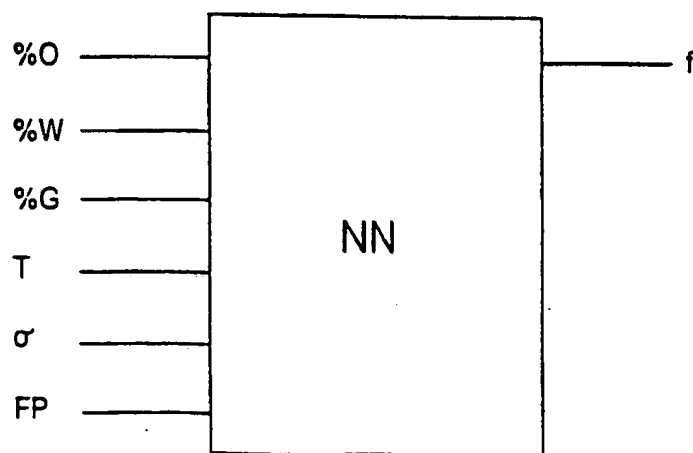


FIG.14.

9/12

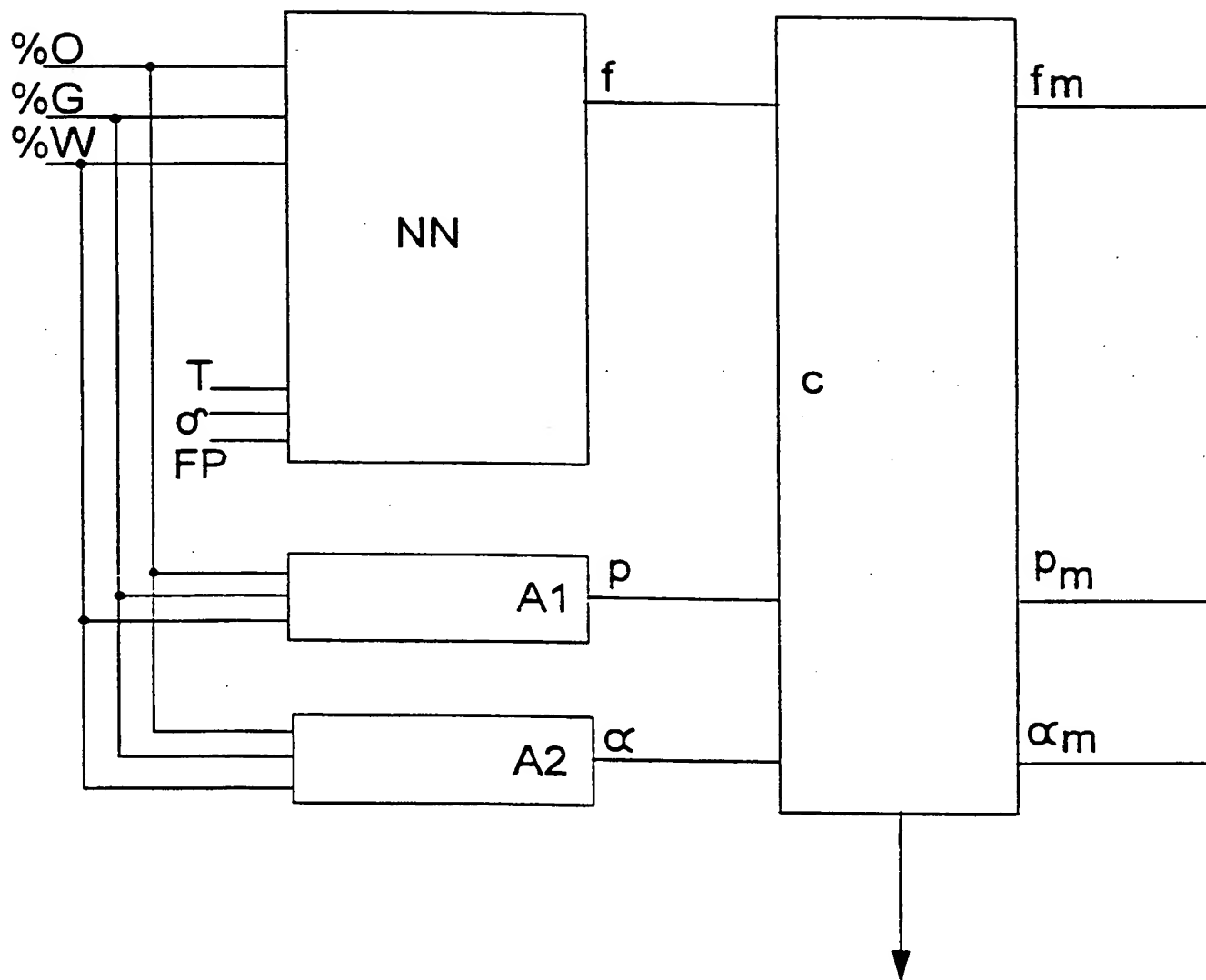


FIG.15.

10/12

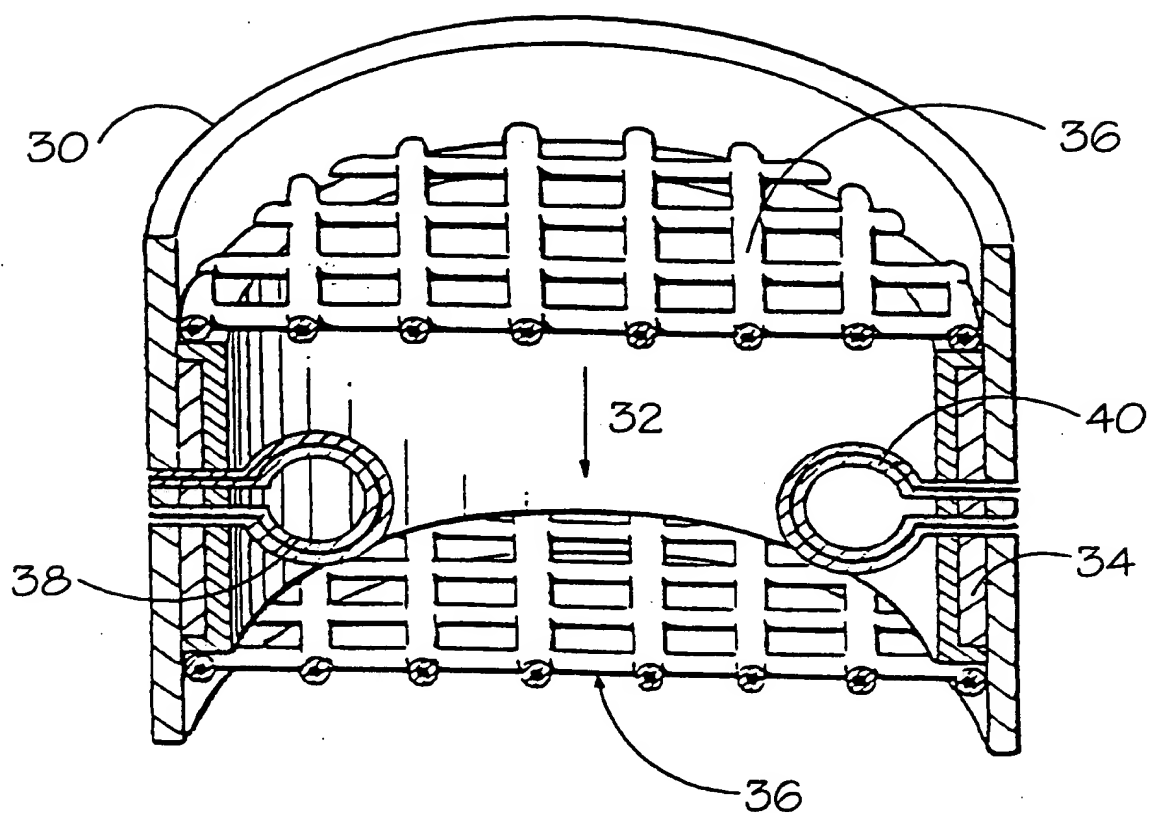


FIG.16.

11/12

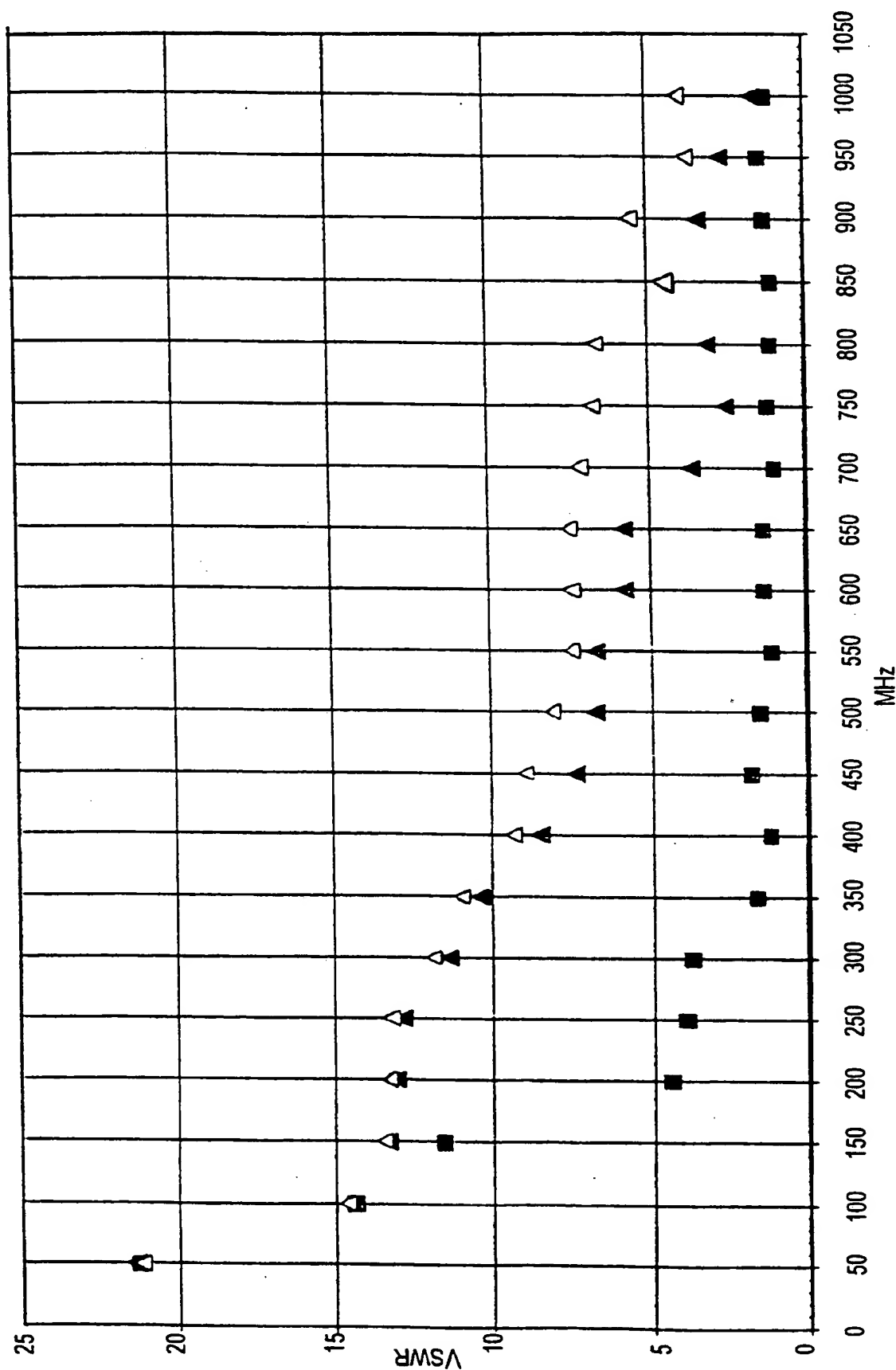


FIG.17.

12/12

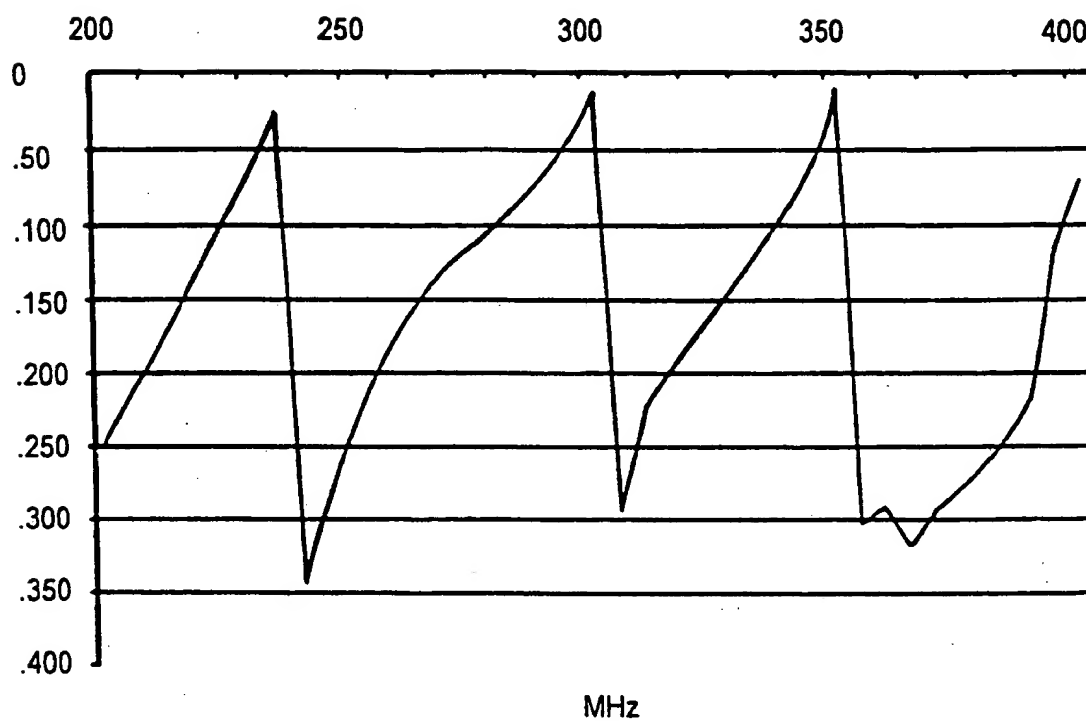


FIG.18.

Inte Application No
PCT/ 00/00168

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01N22/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

20 March 2000

Date of mailing of the international search report

28/03/2000

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